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CONTRACT AF61(052)-833

7 MAY, 1968

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FINAL SCIENTIFIC REPORT

(IN TWO VOLUMES)

MULTILAYER FILTERS FOR THE REGION 0.8 TO 100 MICRONS

S. D. SMITH

J. S. SEELEY

VOLUME 2—ILLUSTRATIONS

UNIVERSITY OF READING
READING, ENGLAND

157

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UNIVERSITY OF READING

READING, ENGLAND.

THIS RESEARCH HAS BEEN SPONSORED BY THE AIR FORCE CAMBRIDGE RESEARCH LABORATORIES UNDER CONTRACT AF61(052)-833 THROUGH THE EUROPEAN OFFICE OF AEROSPACE RESEARCH, OAR, USAF, AS PART OF THE ADVANCED PROJECTS AGENCY'S PROJECT VELA-UNIFORM.

LIST OF ILLUSTRATIONS

DISPERSION AT AN ABSORPTION PEAK

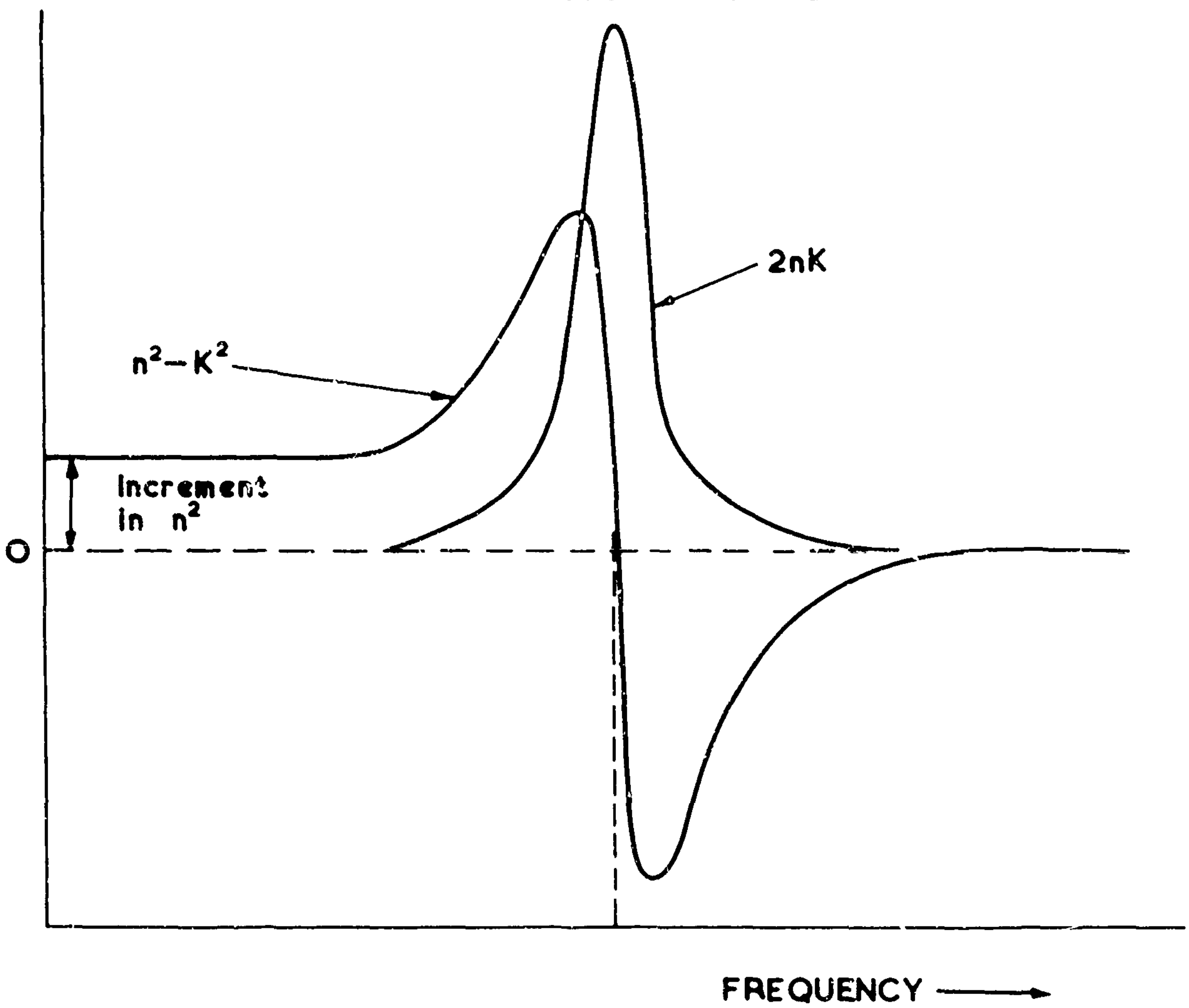
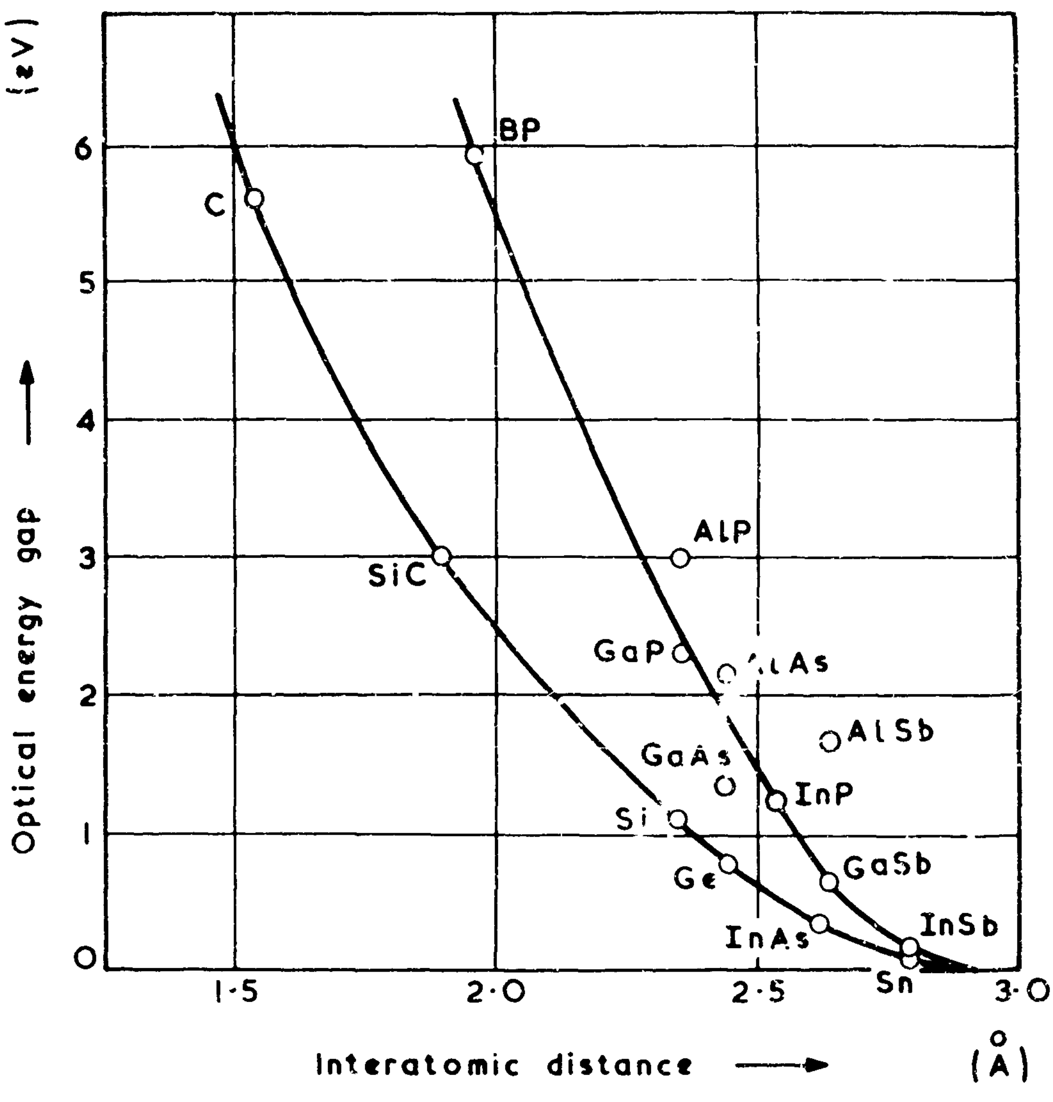
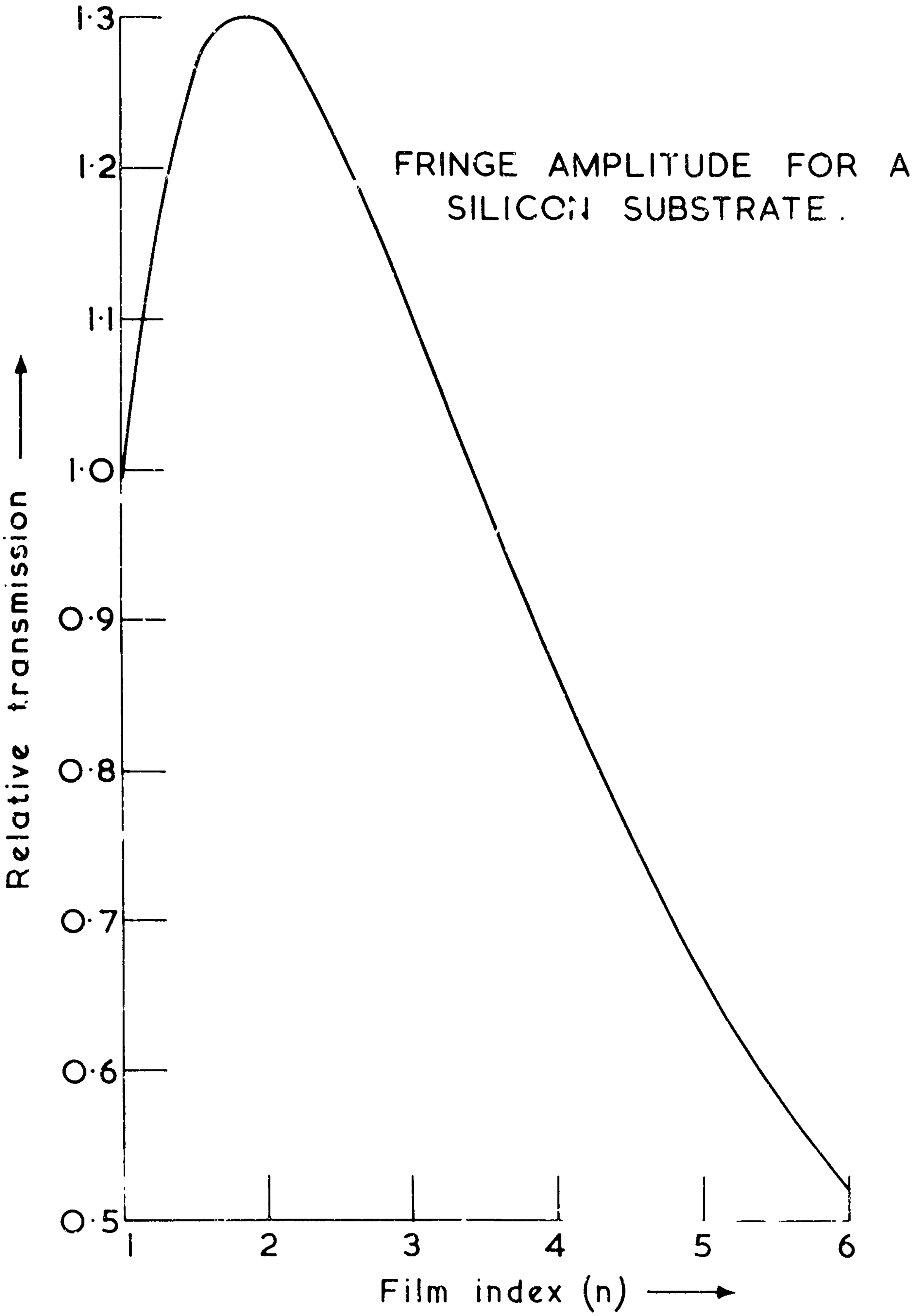


FIG. 2.1



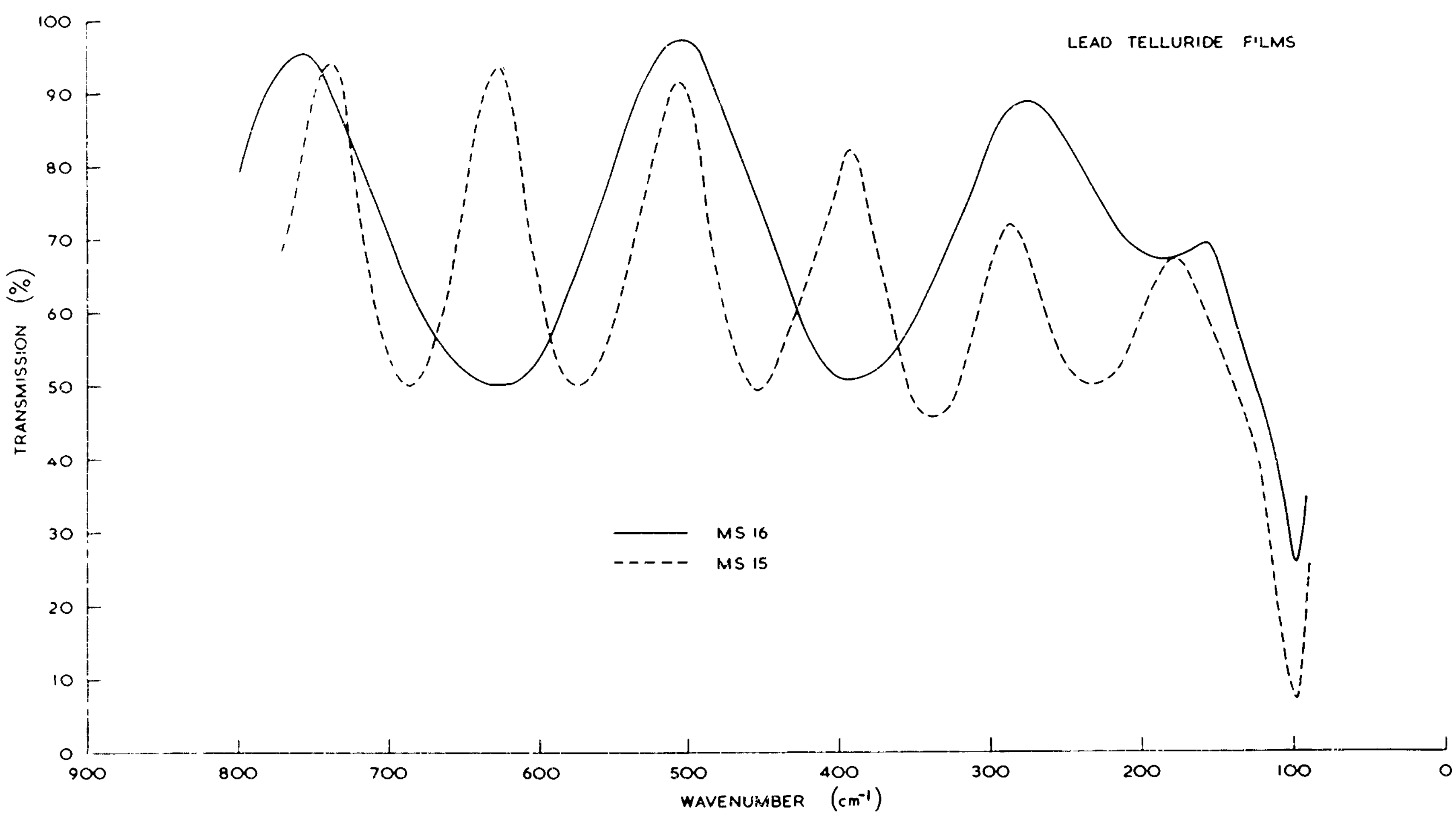
Energy gap of semiconducting Group IV elements and Group III–V compounds of diamond and zinc blende structure

Fig. 2.2



FRINGE AMPLITUDE FOR A SILICON SUBSTRATE.
1·3
1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5
Relative transmission
1
2
3
4
5
6
Film index (n)

FIG. 3·1



LEAD TELLURIDE FILMS
MS 16
MS 15
TRANSMISSION (%)
100
90
80
70
60
50
40
30
20
10
0
900
800
700
600
500
400
300
200
100
0
WAVENUMBER (cm^{-1})

FIG 3 2

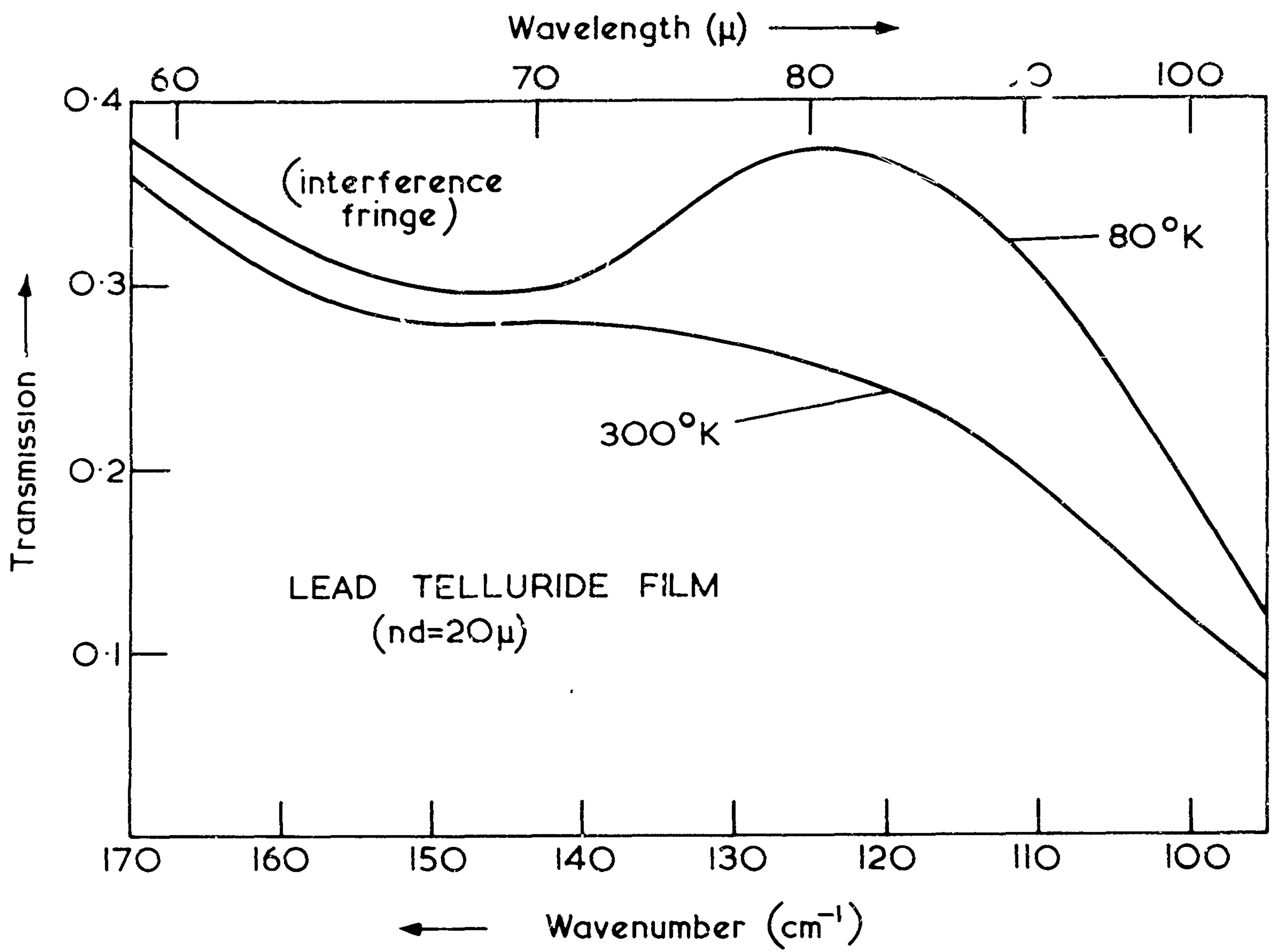
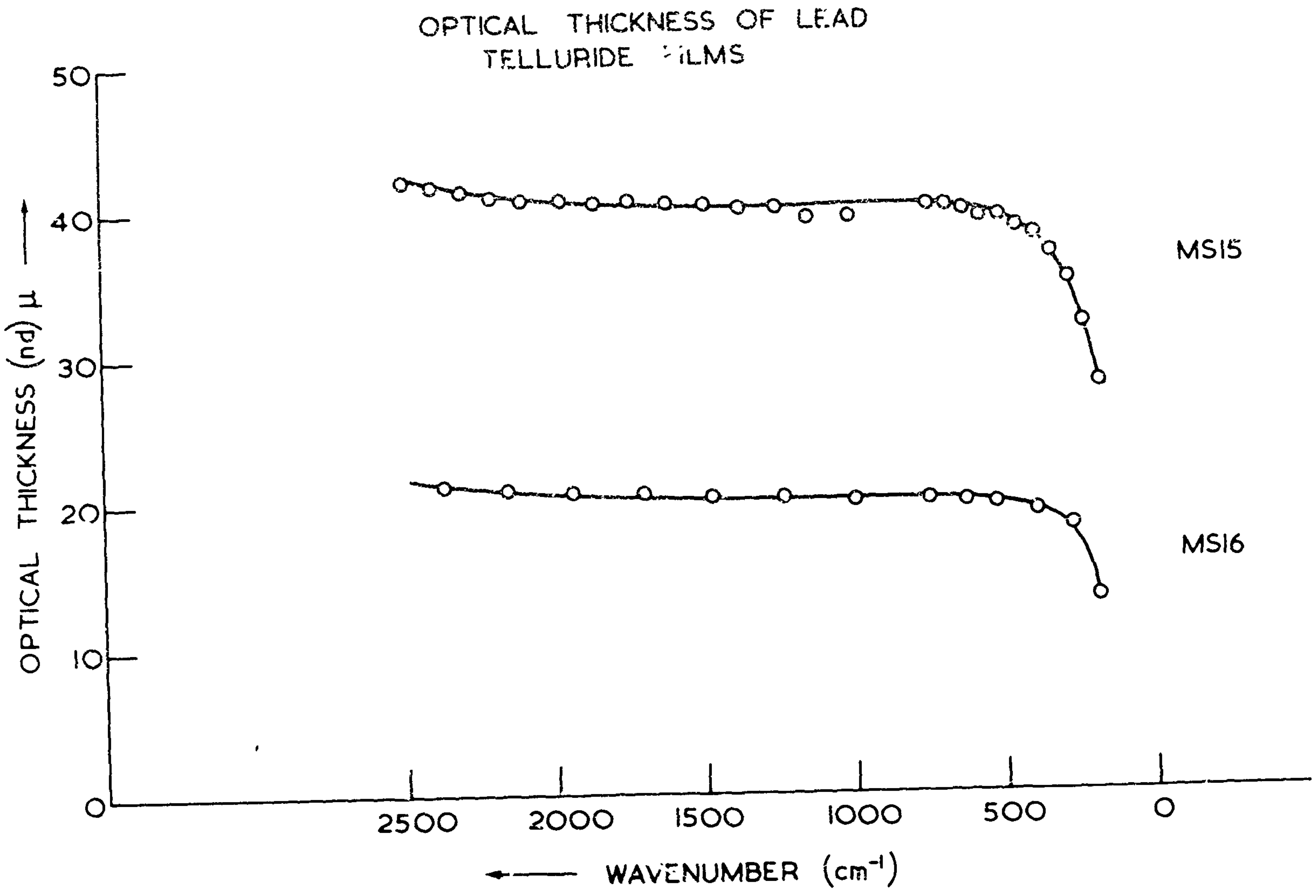
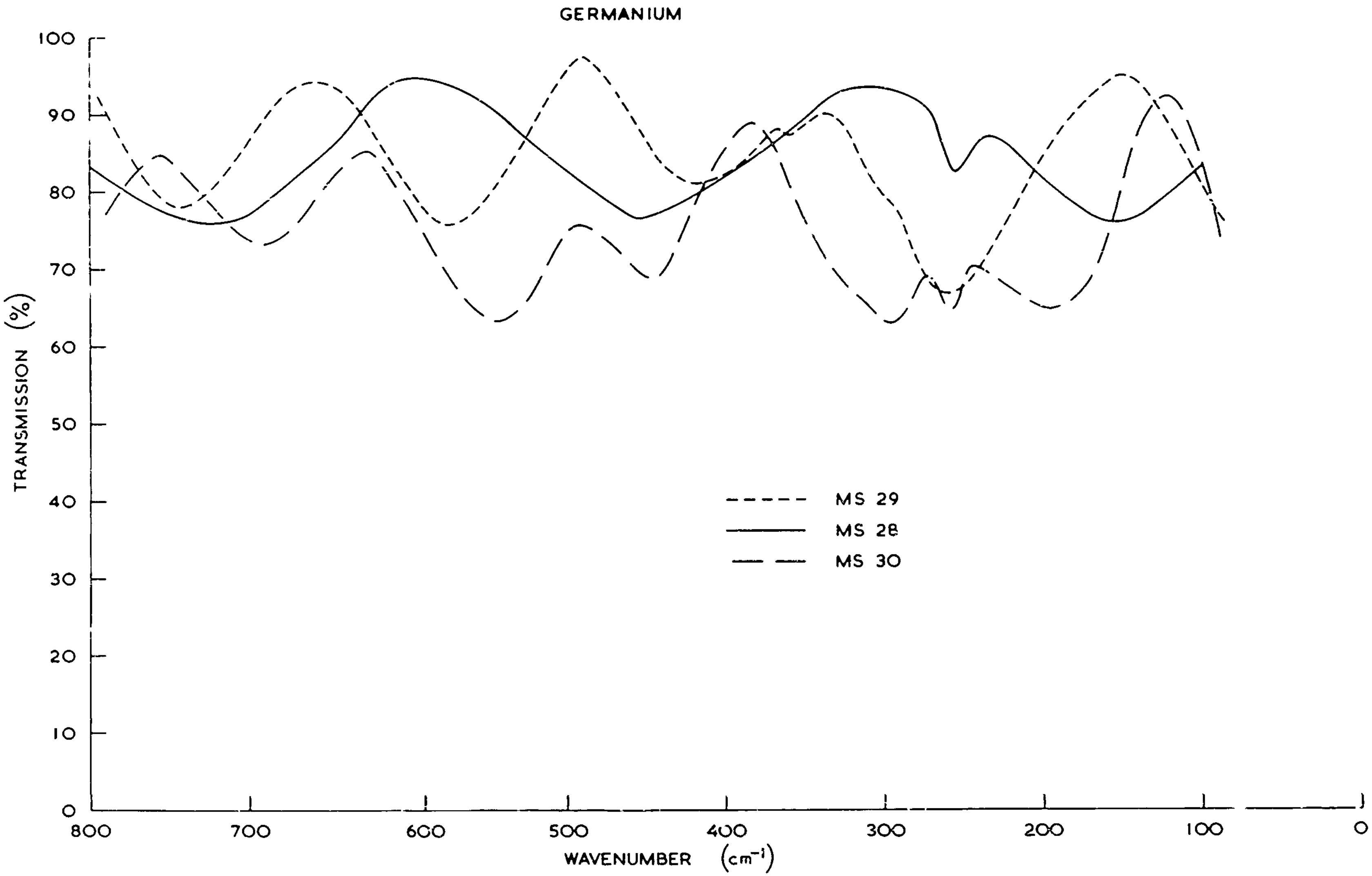

Wavelength (μ)
60
70
80
100
0·4
0·3
0·2
0·1
Transmission
(interference fringe)
80°K
300°K
LEAD TELLURIDE FILM
(nd=20μ)
170
160
150
140
130
120
110
100
Wavenumber (cm⁻¹)

FIG. 3.3



OPTICAL THICKNESS OF LEAD
TELLURIDE FILMS
50
40
30
20
10
0
OPTICAL THICKNESS (nd) μ
MS15
MS16
2500
2000
1500
1000
500
0
WAVENUMBER (cm⁻¹)

FIG. 3.4



GERMANIUM
TRANSMISSION (%)
100
90
80
70
60
50
40
30
20
10
0
800
700
600
500
400
300
200
100
0
WAVENUMBER (cm⁻¹)
MS 29
MS 28
MS 30

FIG 3 5

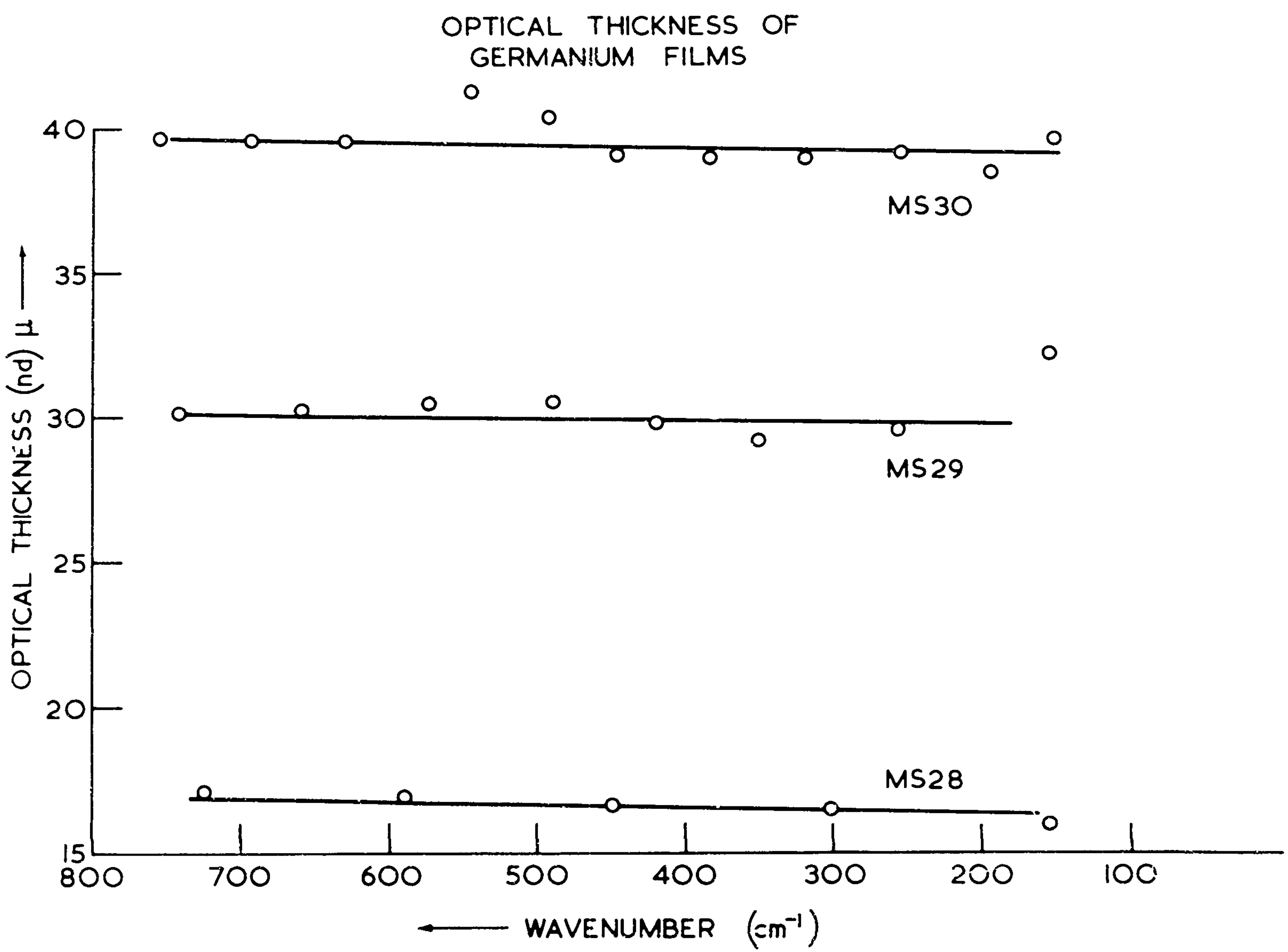

OPTICAL THICKNESS OF
GERMANIUM FILMS
OPTICAL THICKNESS (nd) μ
40
35
30
25
20
15
MS30
MS29
MS28
800
700
600
500
400
300
200
100
WAVENUMBER (cm⁻¹)

FIG. 3.6

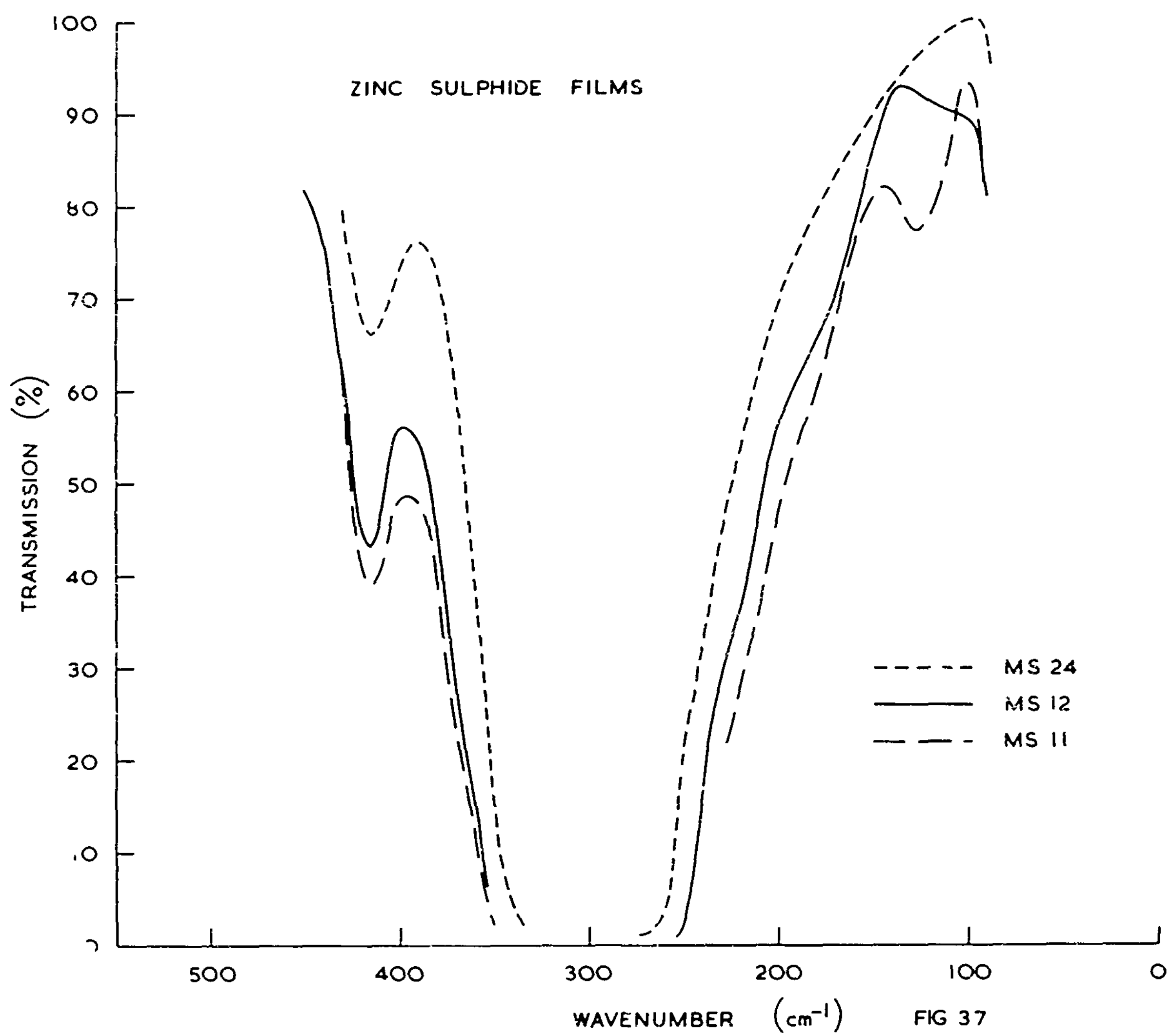

ZINC SULPHIDE FILMS
TRANSMISSION (%)
100
90
80
70
60
50
40
30
20
10
0
500
400
300
200
100
0
WAVENUMBER (cm^{-1})
MS 24
MS 12
MS 11

FIG 37

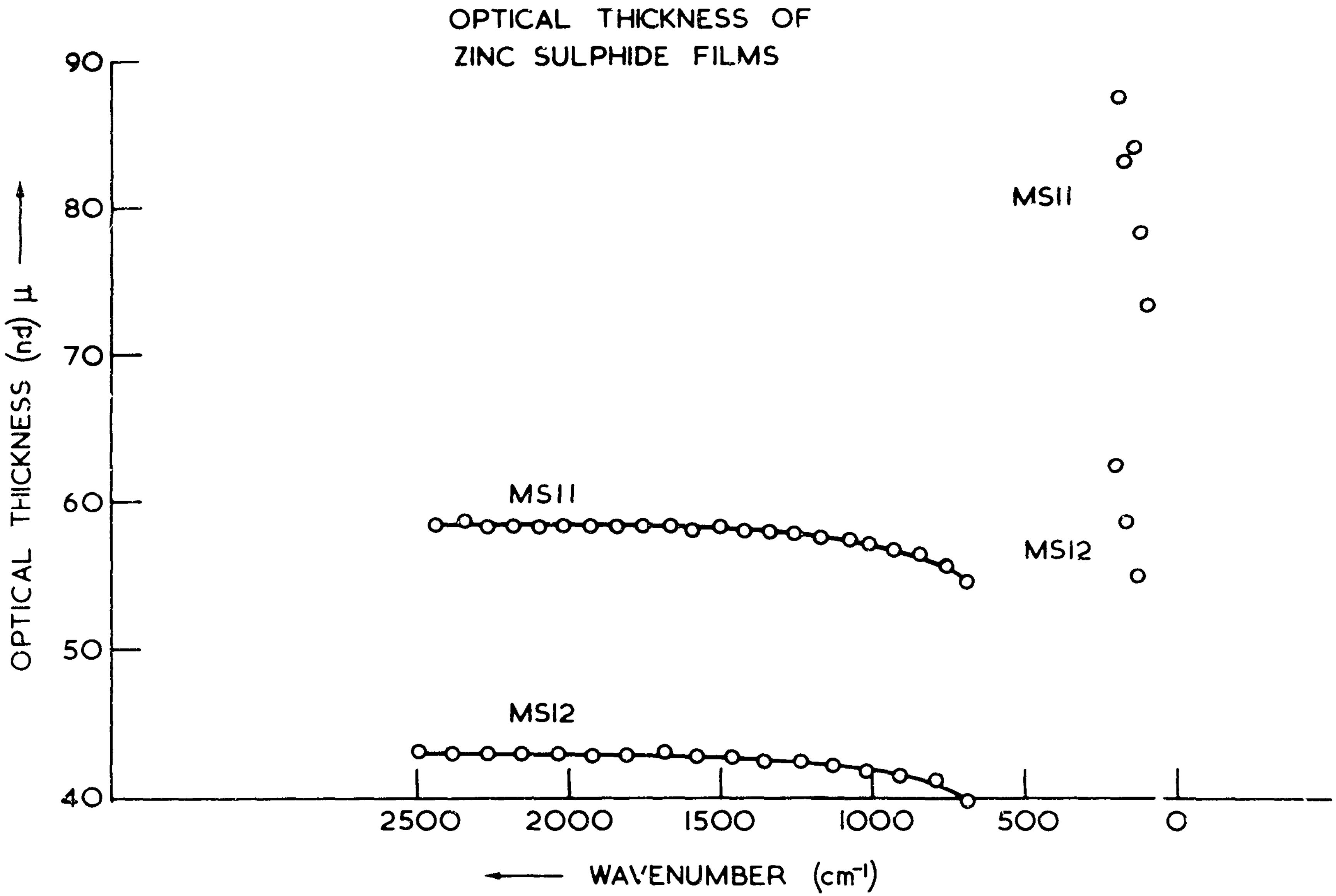

OPTICAL THICKNESS OF
ZINC SULPHIDE FILMS
90
80
70
60
50
40
OPTICAL THICKNESS (nd) μ
MS11
MS12
MS11
MS12
2500
2000
1500
1000
500
0
WAVENUMBER (cm⁻¹)

FIG. 3.8

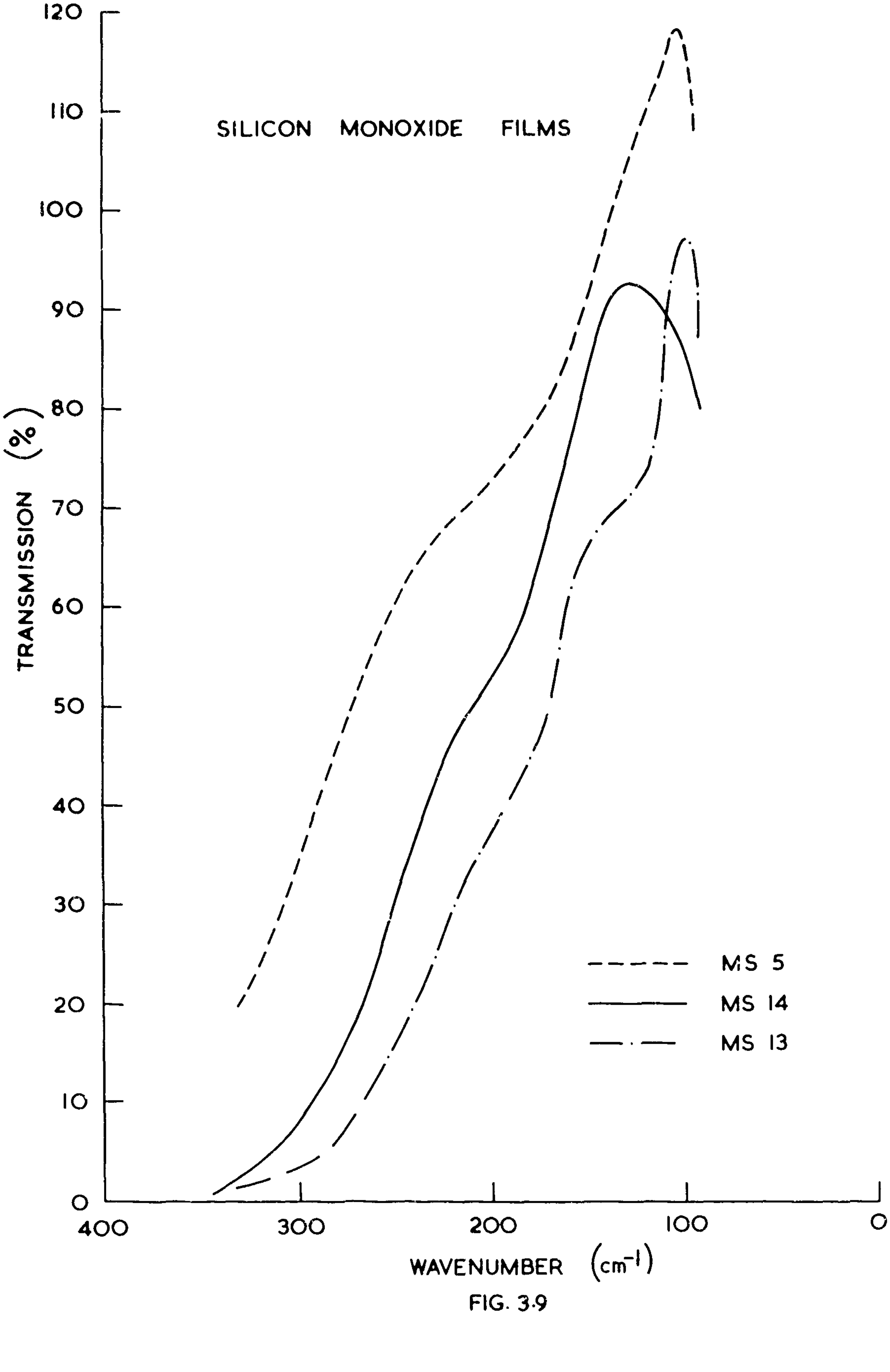
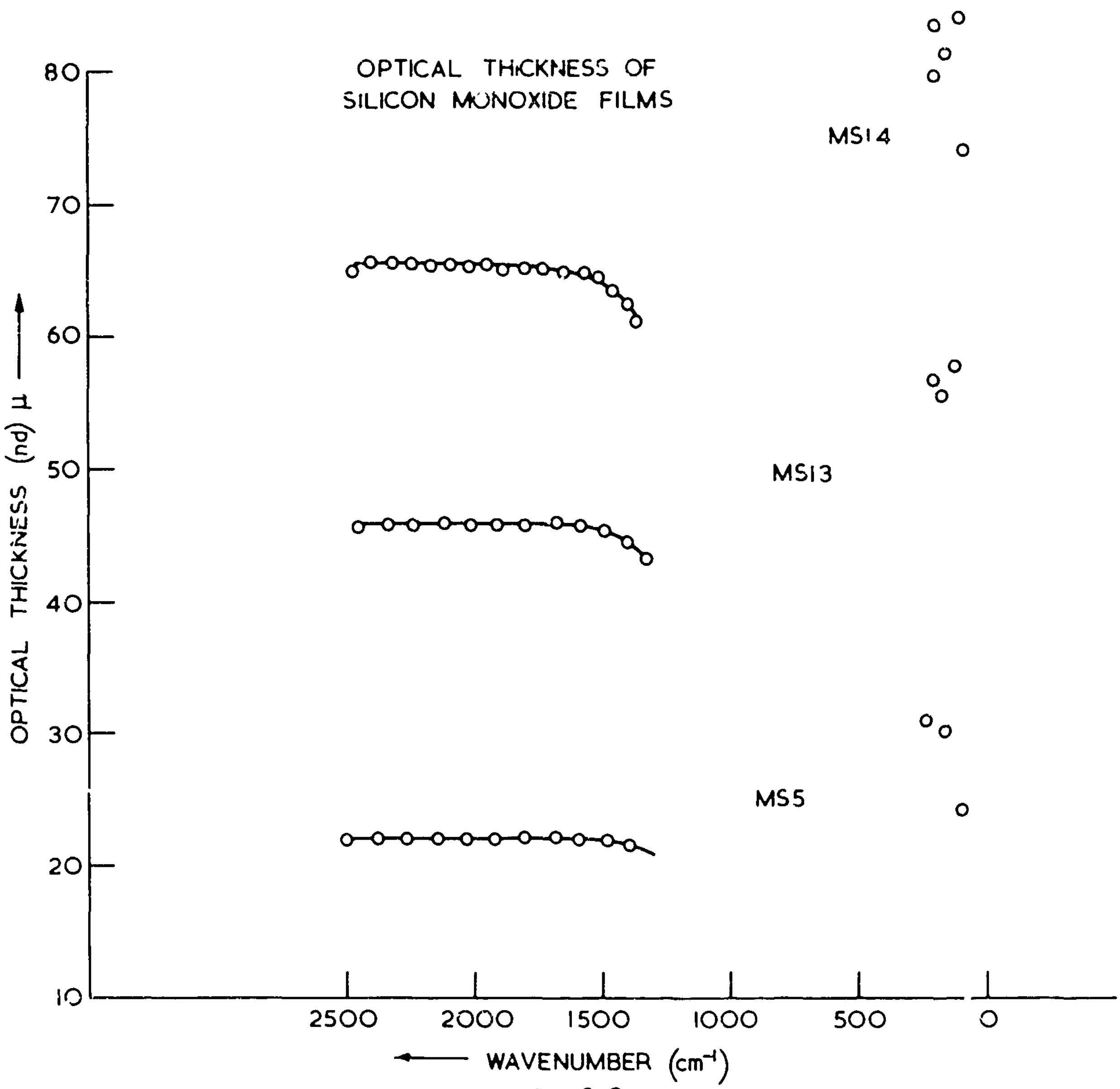

SILICON MONOXIDE FILMS
TRANSMISSION (%)
WAVENUMBER (cm⁻¹)
MS 5
MS 14
MS 13
120
110
100
90
80
70
60
50
40
30
20
10
0
400
300
200
100
0

FIG. 3·9


OPTICAL THICKNESS OF
SILICON MONOXIDE FILMS
80
70
60
50
40
30
20
10
OPTICAL THICKNESS (nd) µ
MS14
MS13
MS5
2500
2000
1500
1000
500
0
WAVENUMBER (cm⁻¹)
FIG 3.10

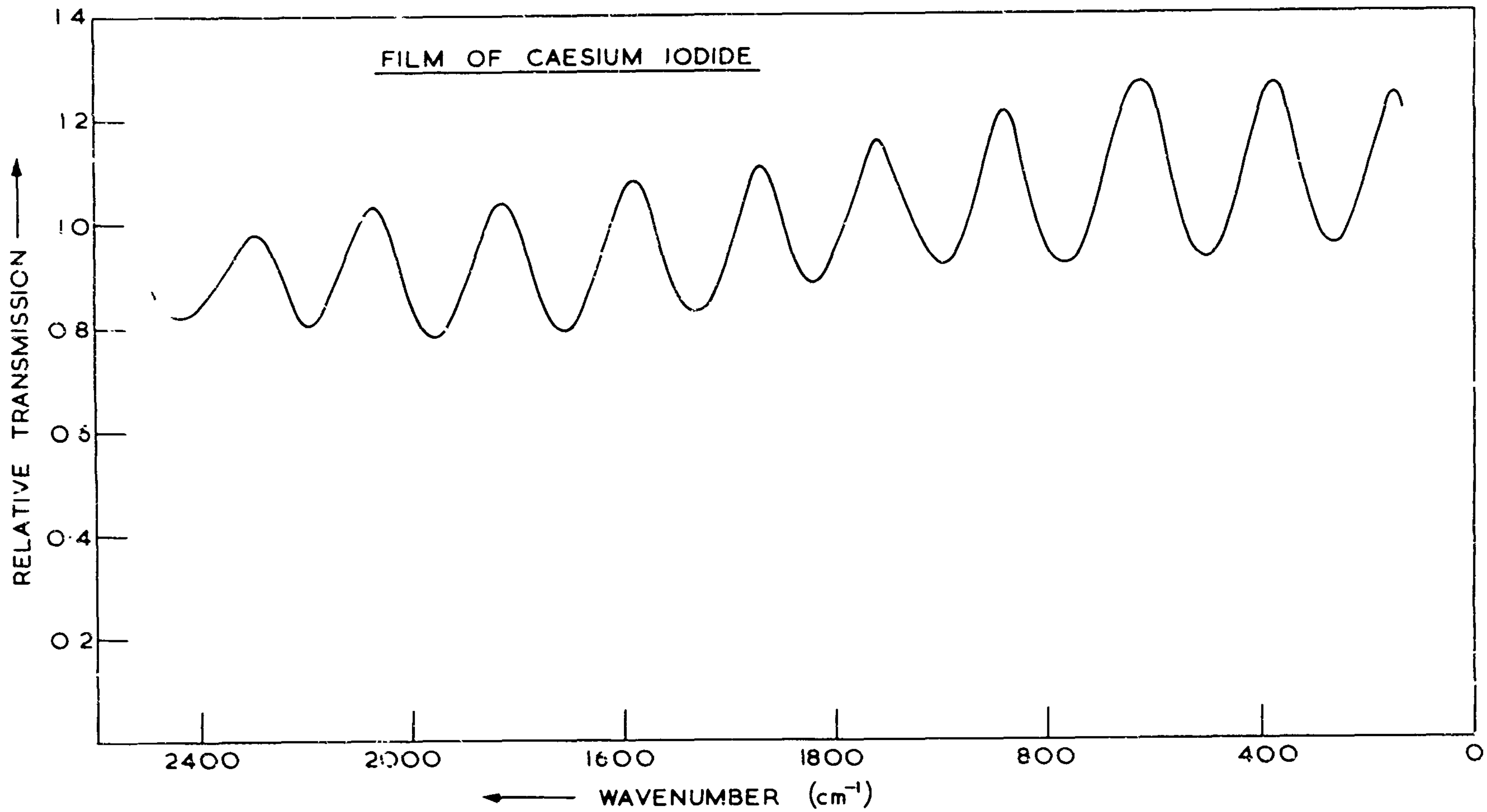
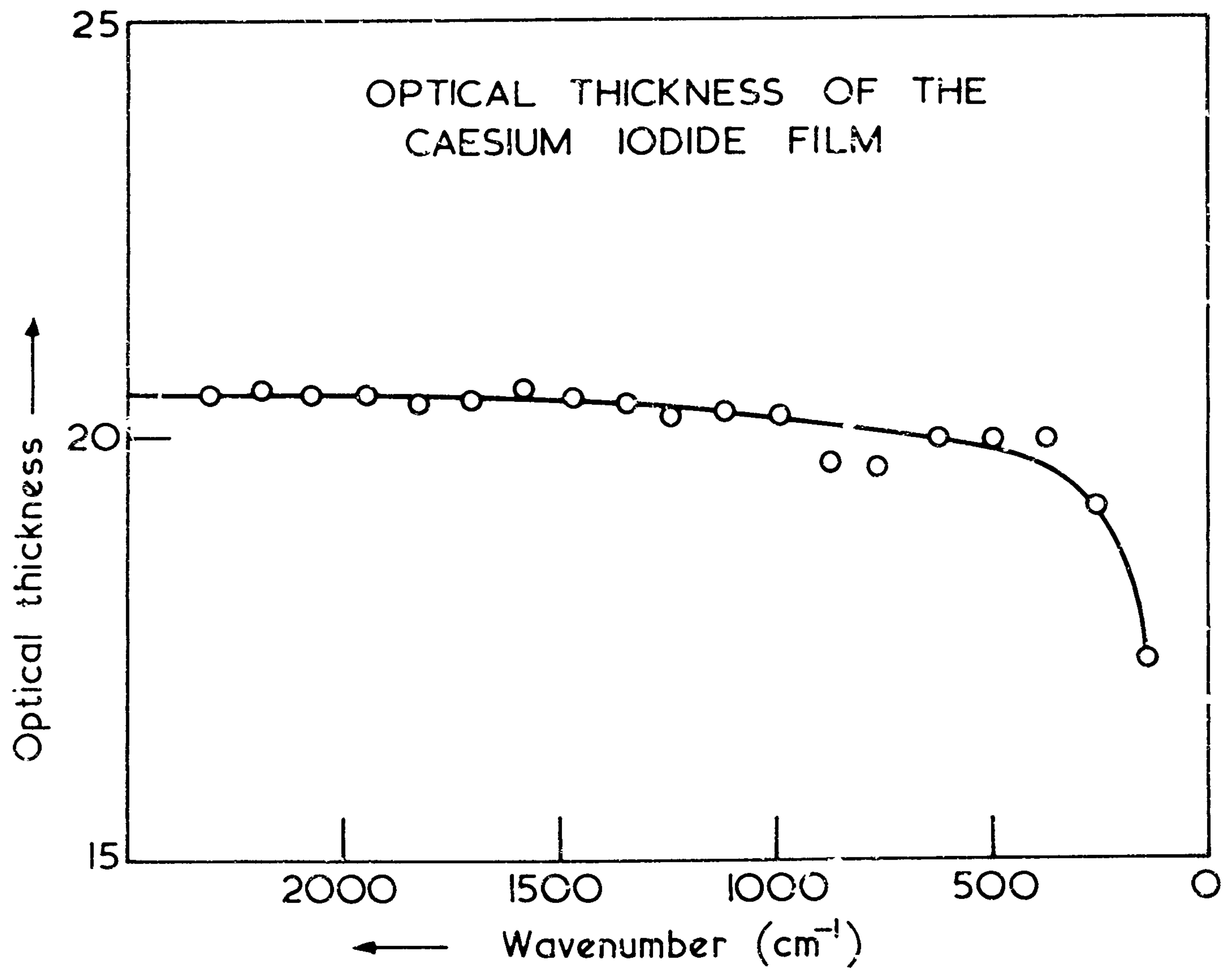

FILM OF CAESIUM IODIDE
RELATIVE TRANSMISSION
1·4
1·2
1·0
0·8
0·6
0·4
0·2
2400
2000
1600
1800
800
400
0
WAVENUMBER (cm⁻¹)

FIG. 3.11



OPTICAL THICKNESS OF THE
CAESIUM IODIDE FILM
25
20
15
Optical thickness
2000
1500
1000
500
0
Wavenumber (cm^{-1})

FIG. 3.12

FIG. 3.13 (a) TRANSMISSION of CAESIUM BROMIDE

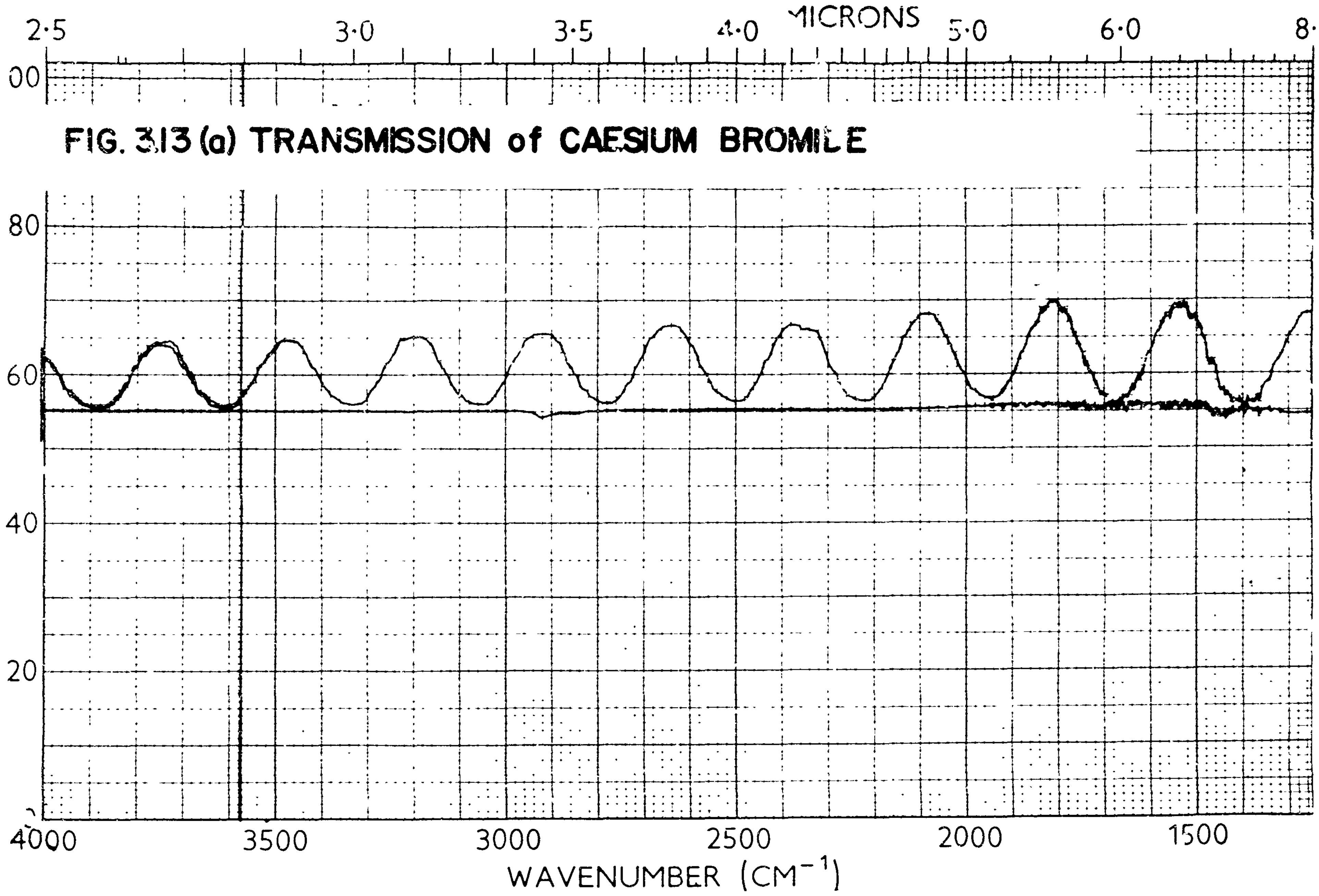
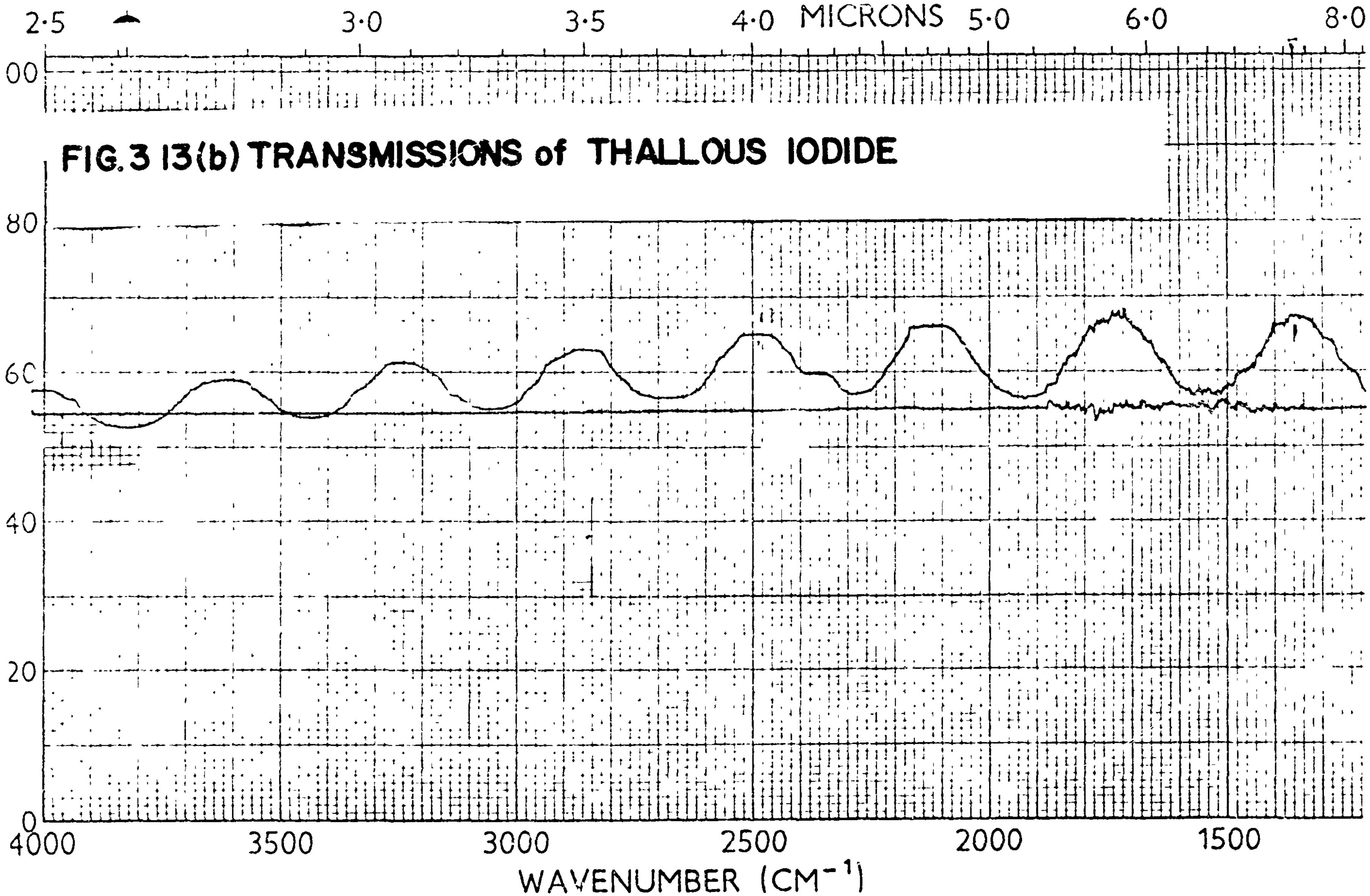


FIG. 3 13(b) TRANSMISSIONS of THALLOUS IODIDE



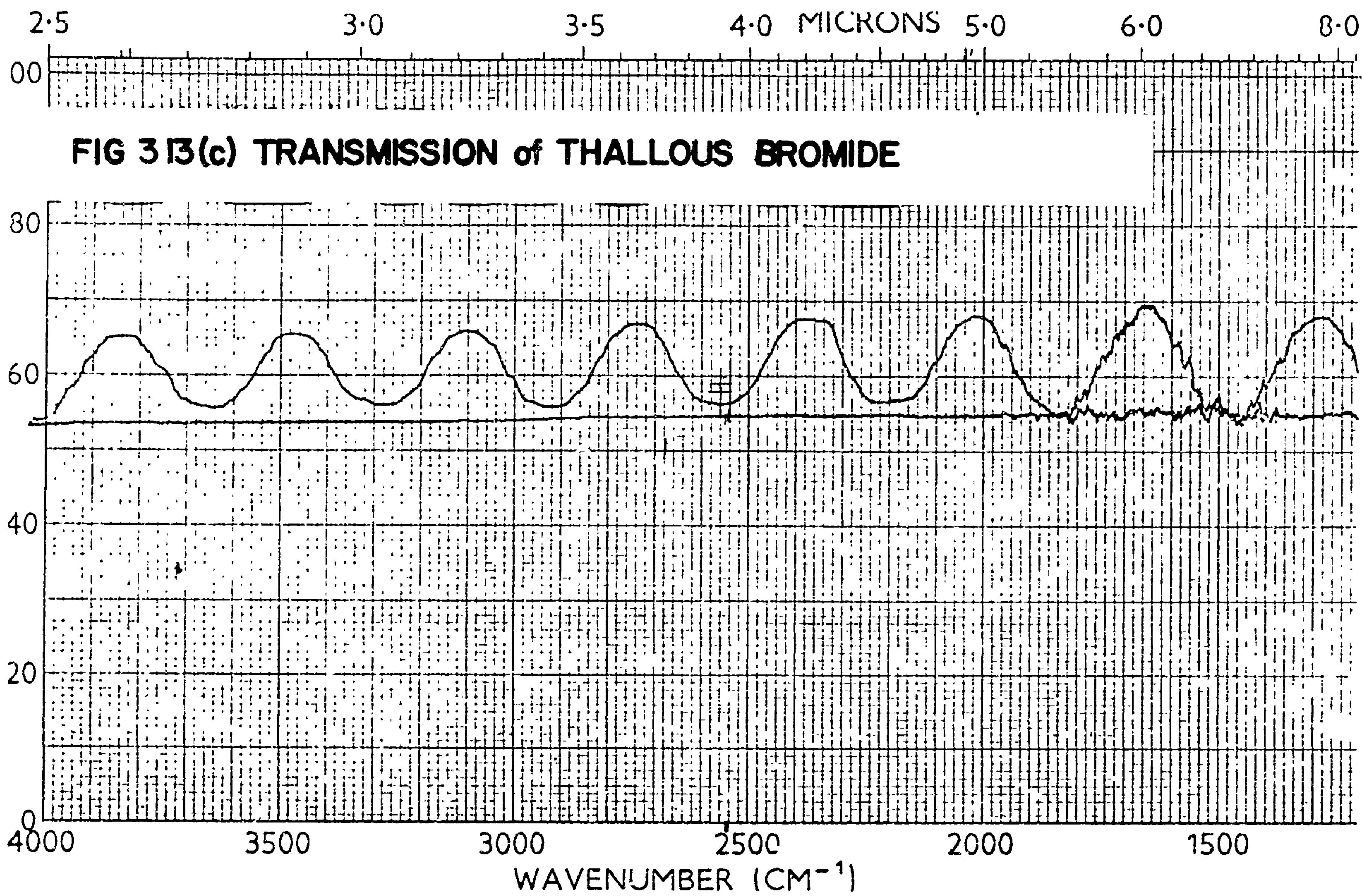


FIG 3 13(c) TRANSMISSION of THALLOUS BROMIDE

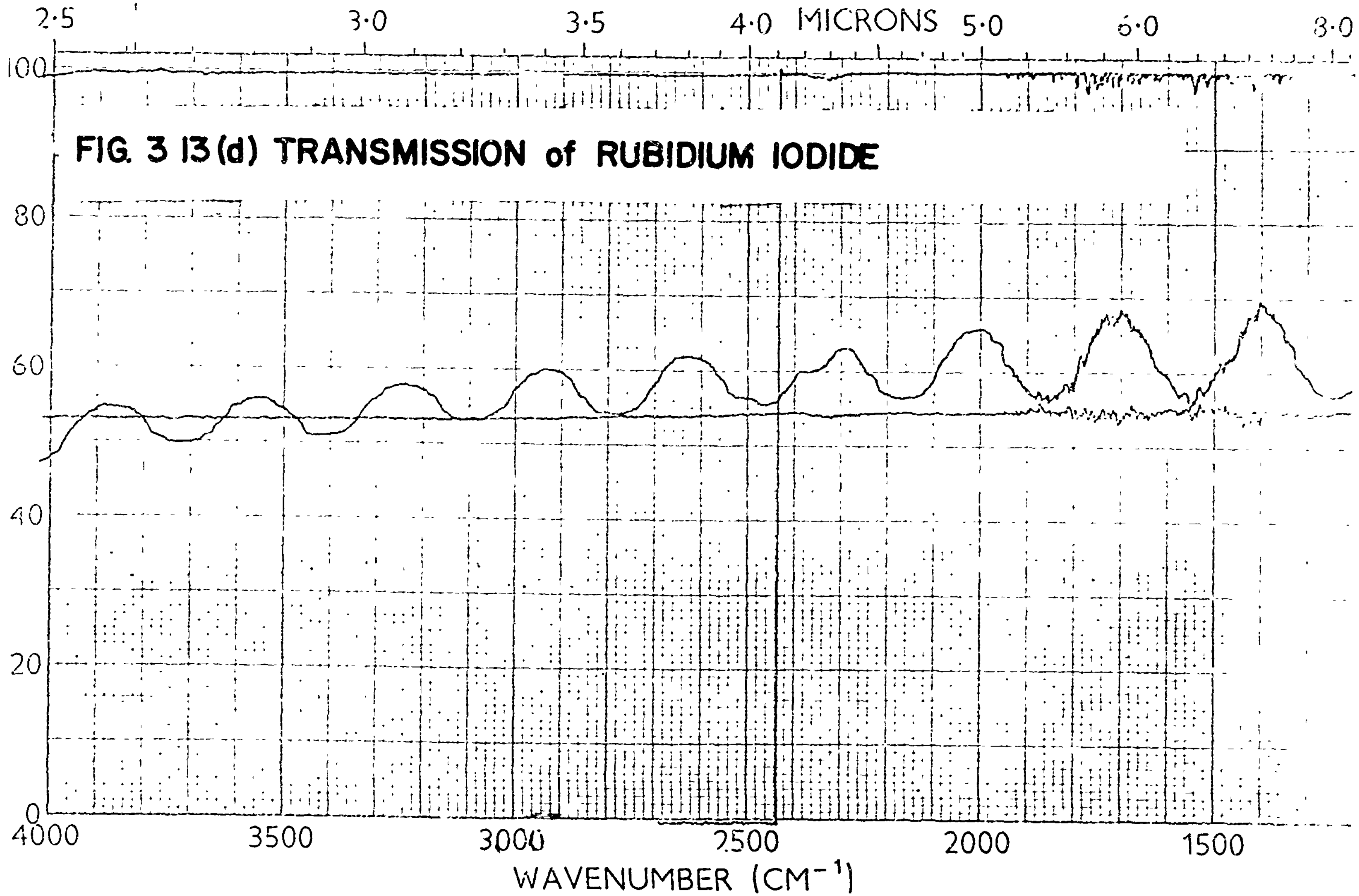


FIG. 3 13(d) TRANSMISSION of RUBIDIUM IODIDE

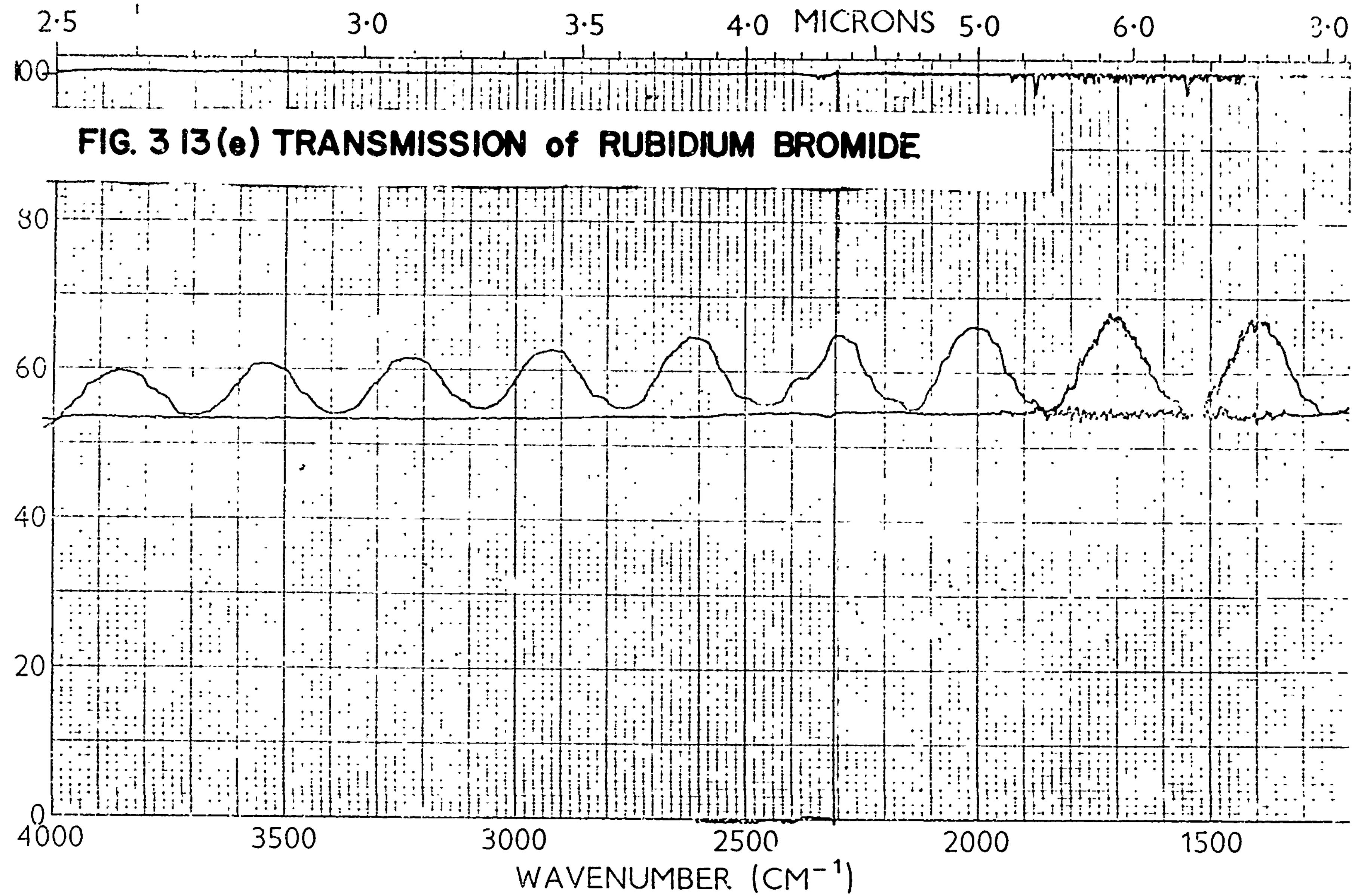


FIG. 3 13(e) TRANSMISSION of RUBIDIUM BROMIDE
MICRONS
2·5
3·0
3·5
4·0
5·0
6·0
3·0
100
80
60
40
20
0
4000
3500
3000
2500
2000
1500
WAVENUMBER (CM^{-1})

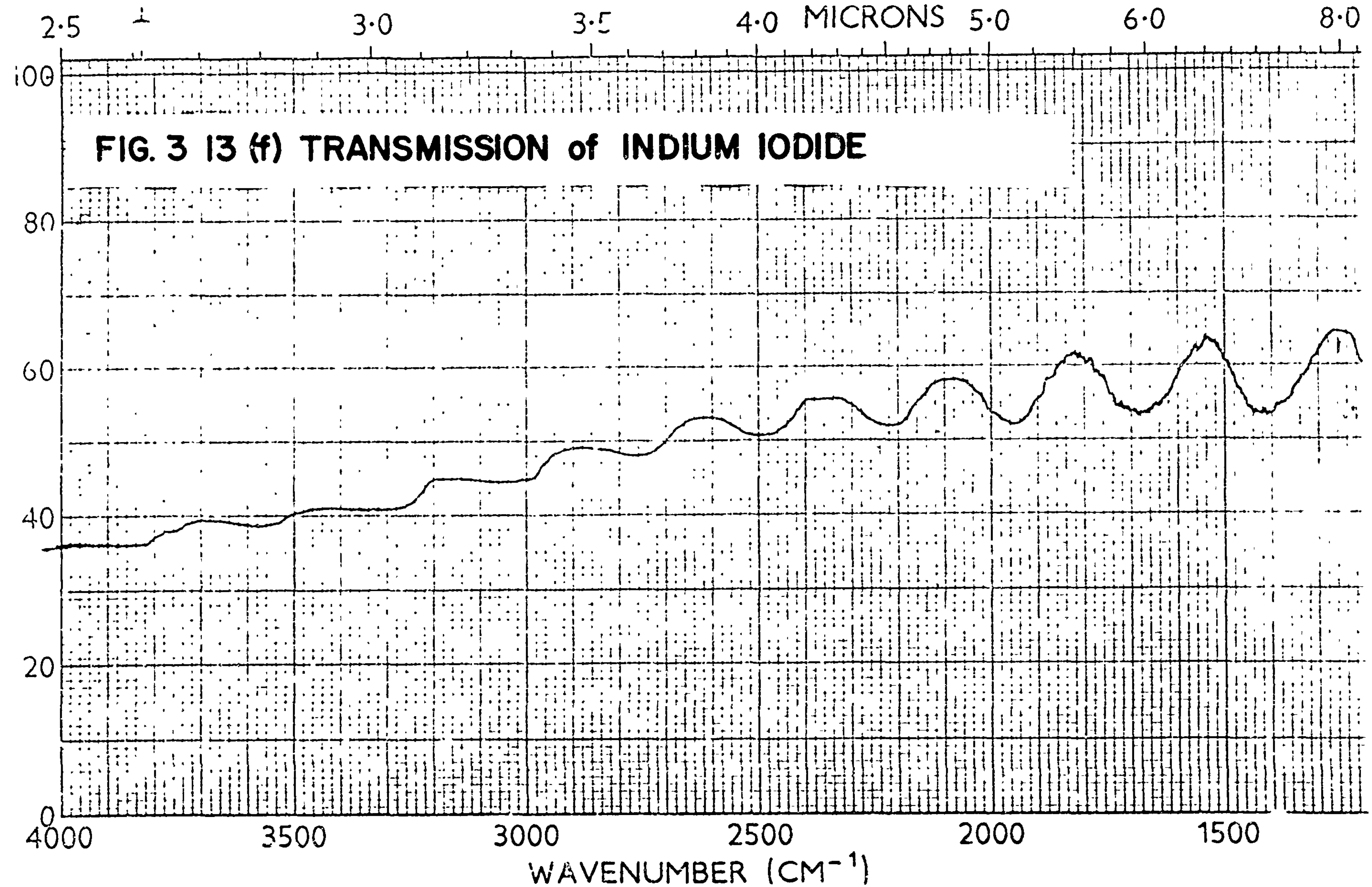


FIG. 3 13 (f) TRANSMISSION of INDIUM IODIDE

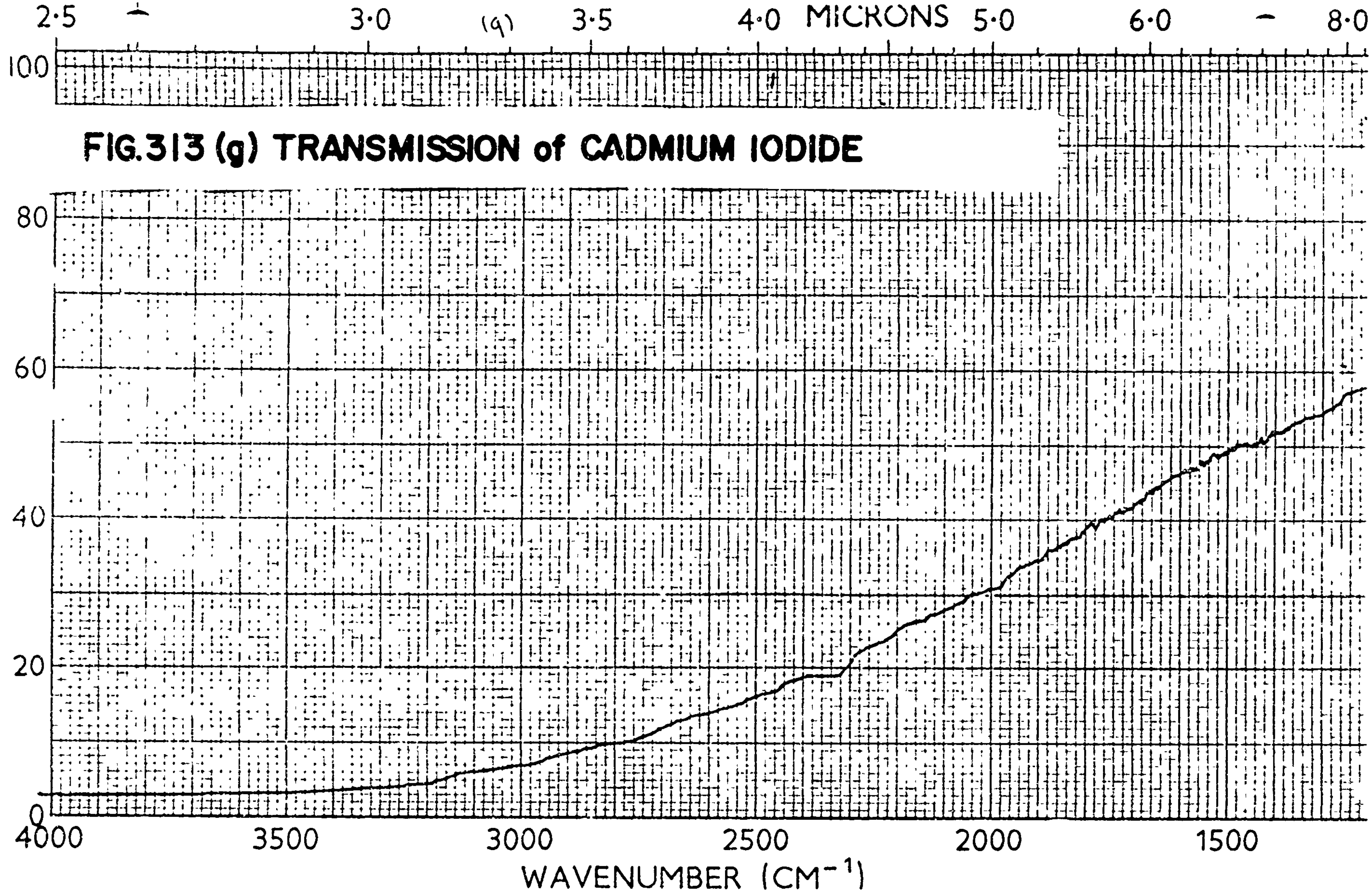


FIG.313 (g) TRANSMISSION of CADMIUM IODIDE

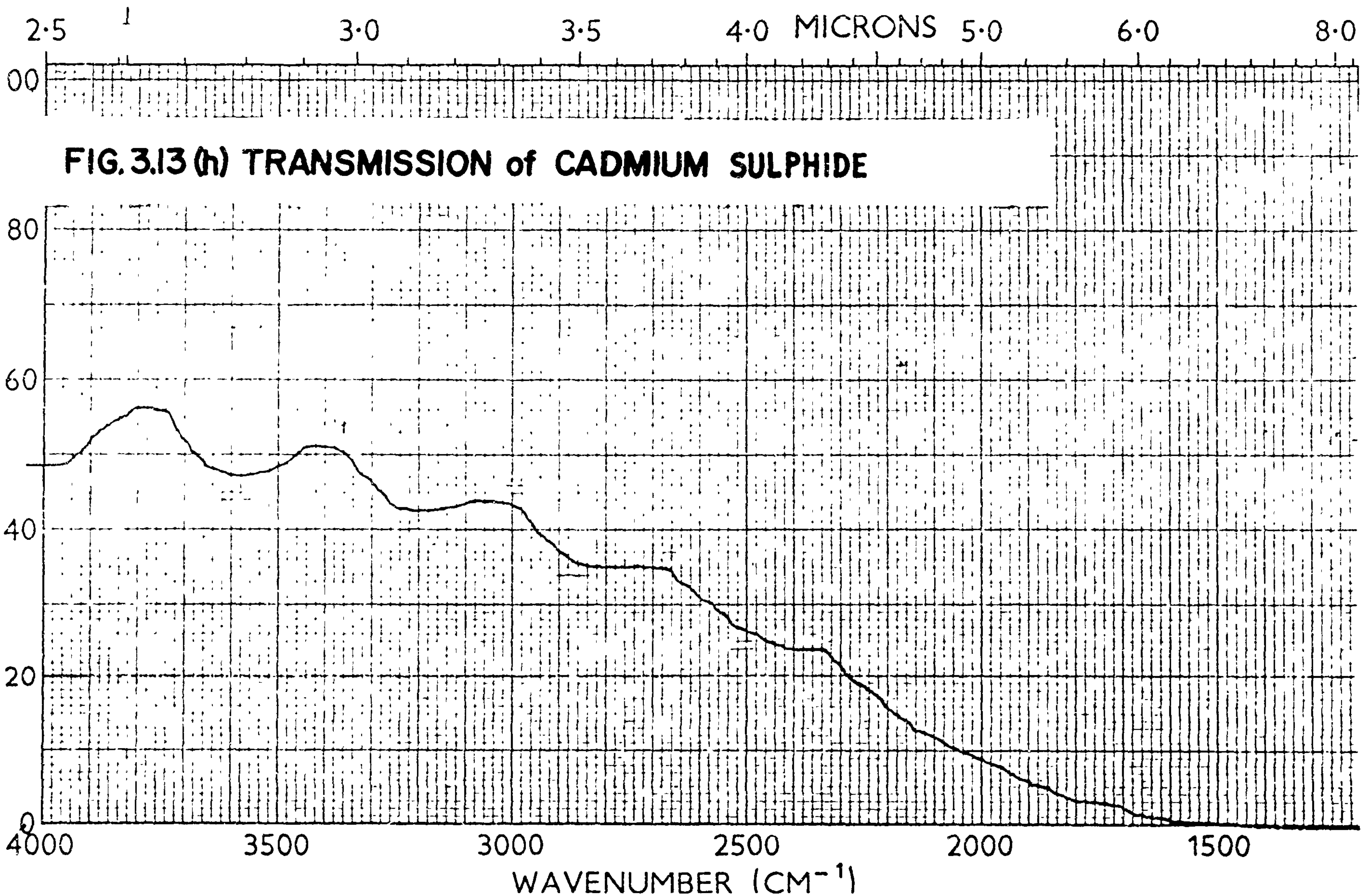


FIG. 3.13 (h) TRANSMISSION of CADMIUM SULPHIDE

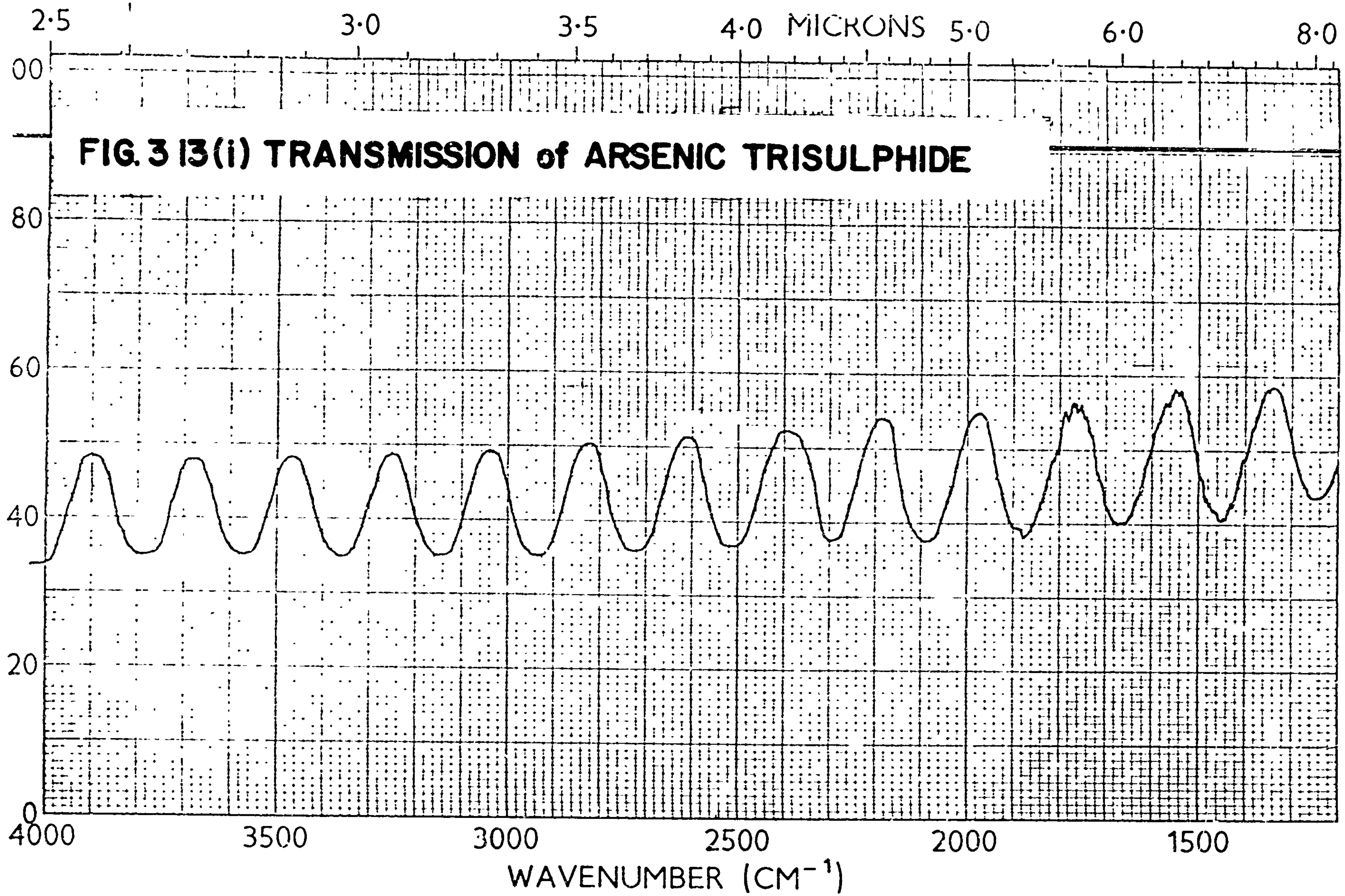


FIG. 3 13(i) TRANSMISSION of ARSENIC TRISULPHIDE

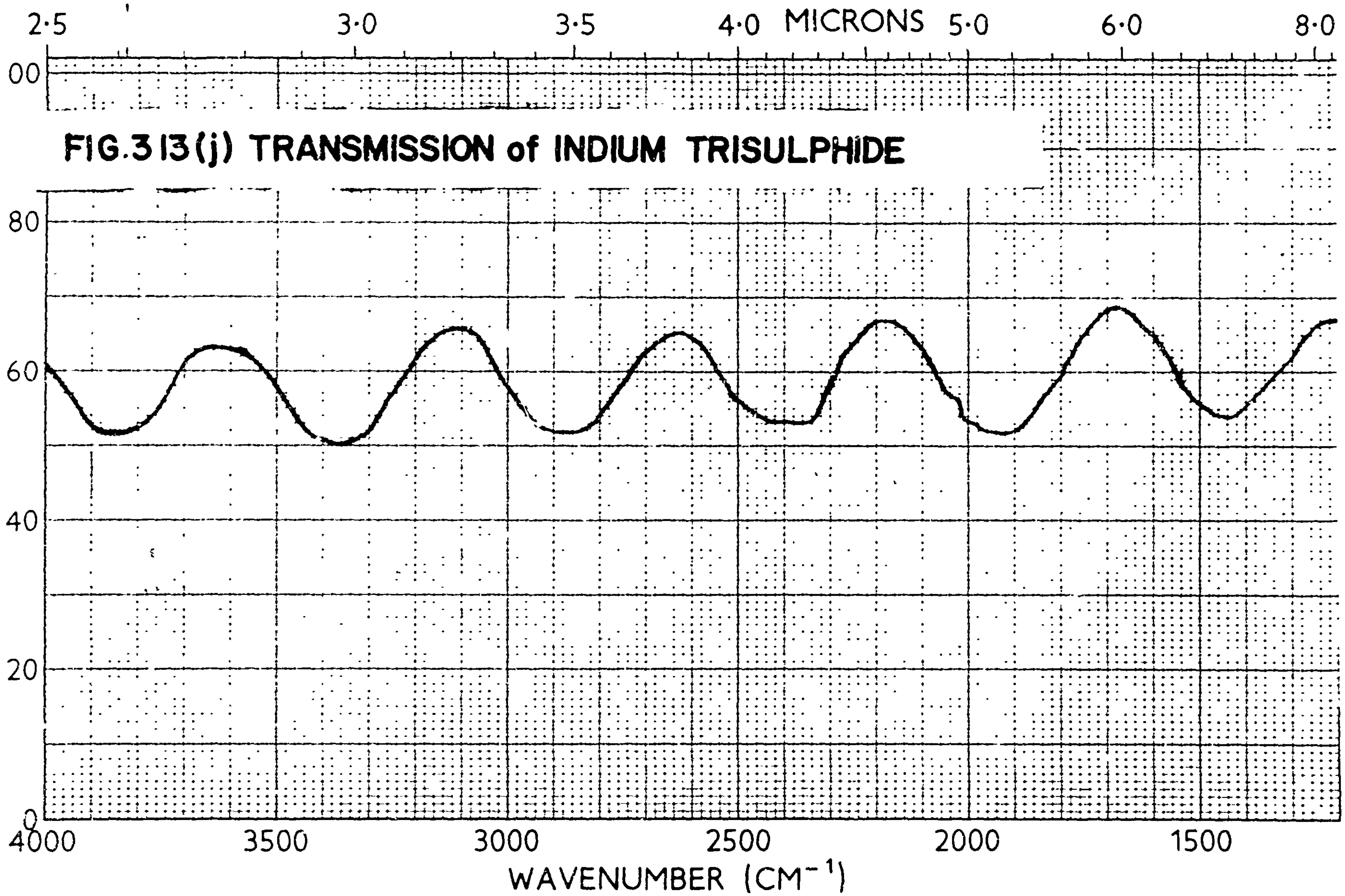


FIG.3 13(j) TRANSMISSION of INDIUM TRISULPHIDE

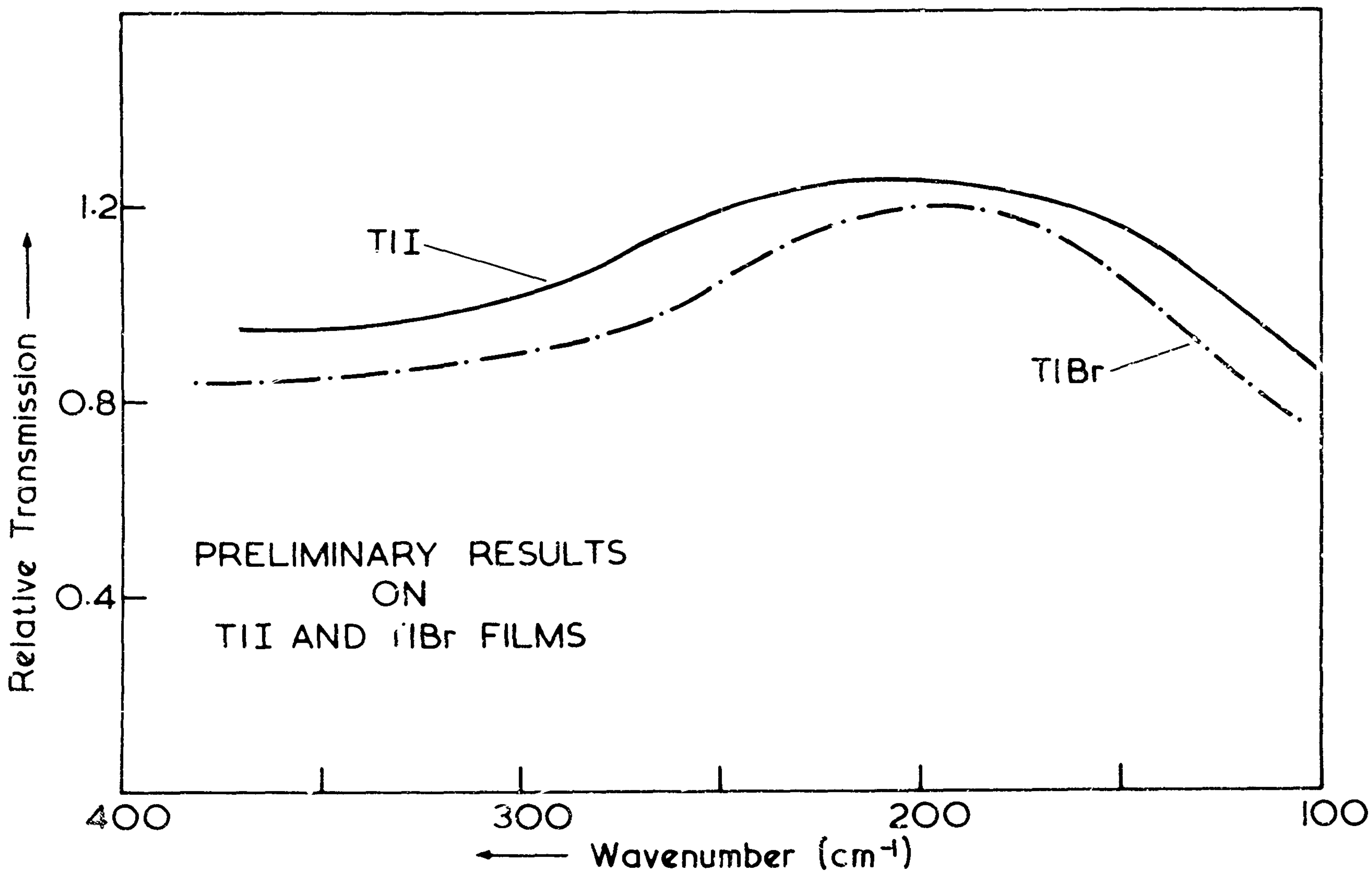

Relative Transmission
1.2
0.8
0.4
TlI
TlBr
PRELIMINARY RESULTS
ON
TlI AND TlBr FILMS
400
300
200
100
Wavenumber (cm⁻¹)

FIG. 3.14

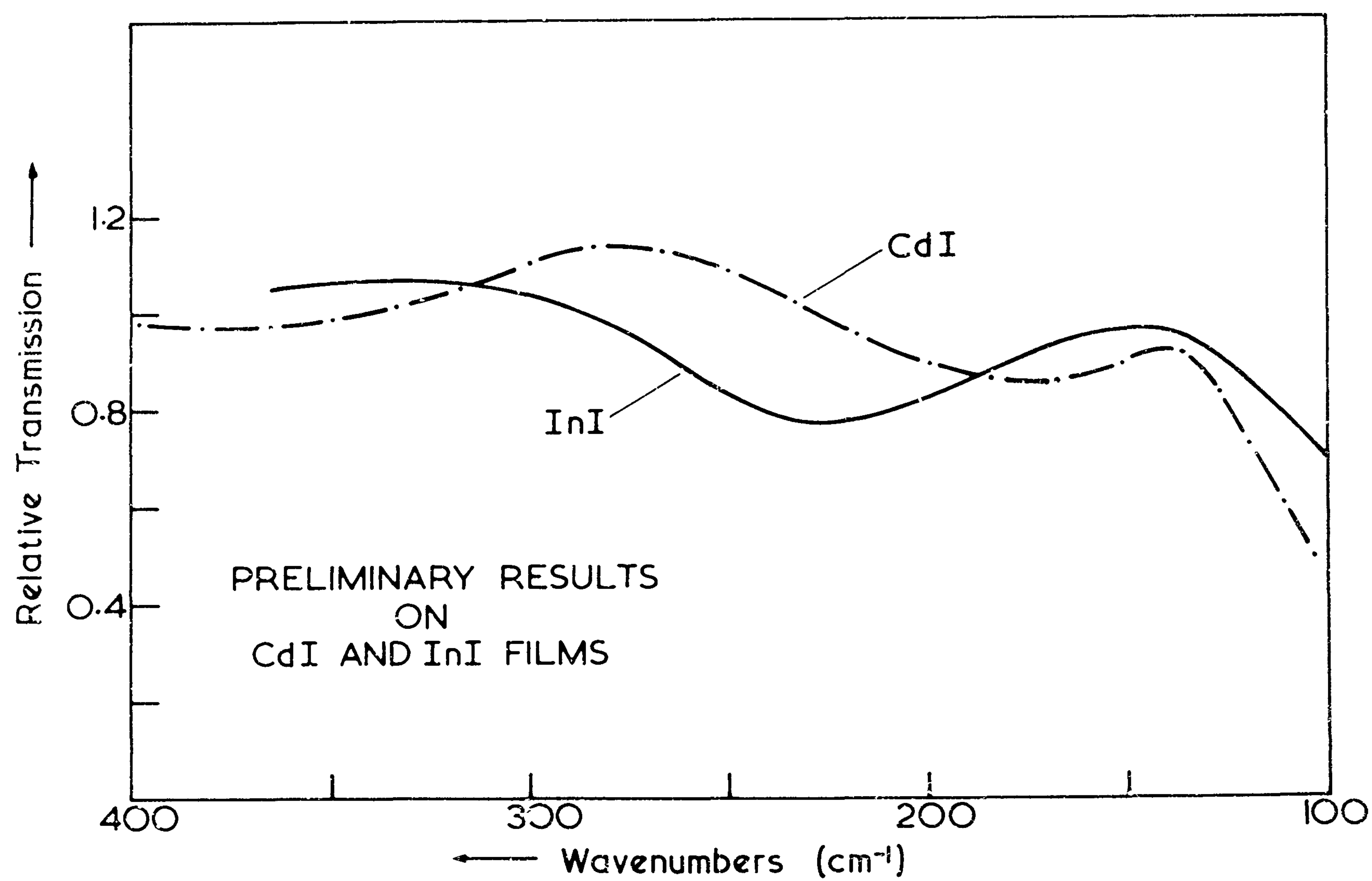

Relative Transmission
1.2
0.8
0.4
CdI
InI
PRELIMINARY RESULTS
ON
CdI AND InI FILMS
400
300
200
100
Wavenumbers (cm⁻¹)

FIG. 3.15

HIGH VAPOUR PRESSURE METHOD

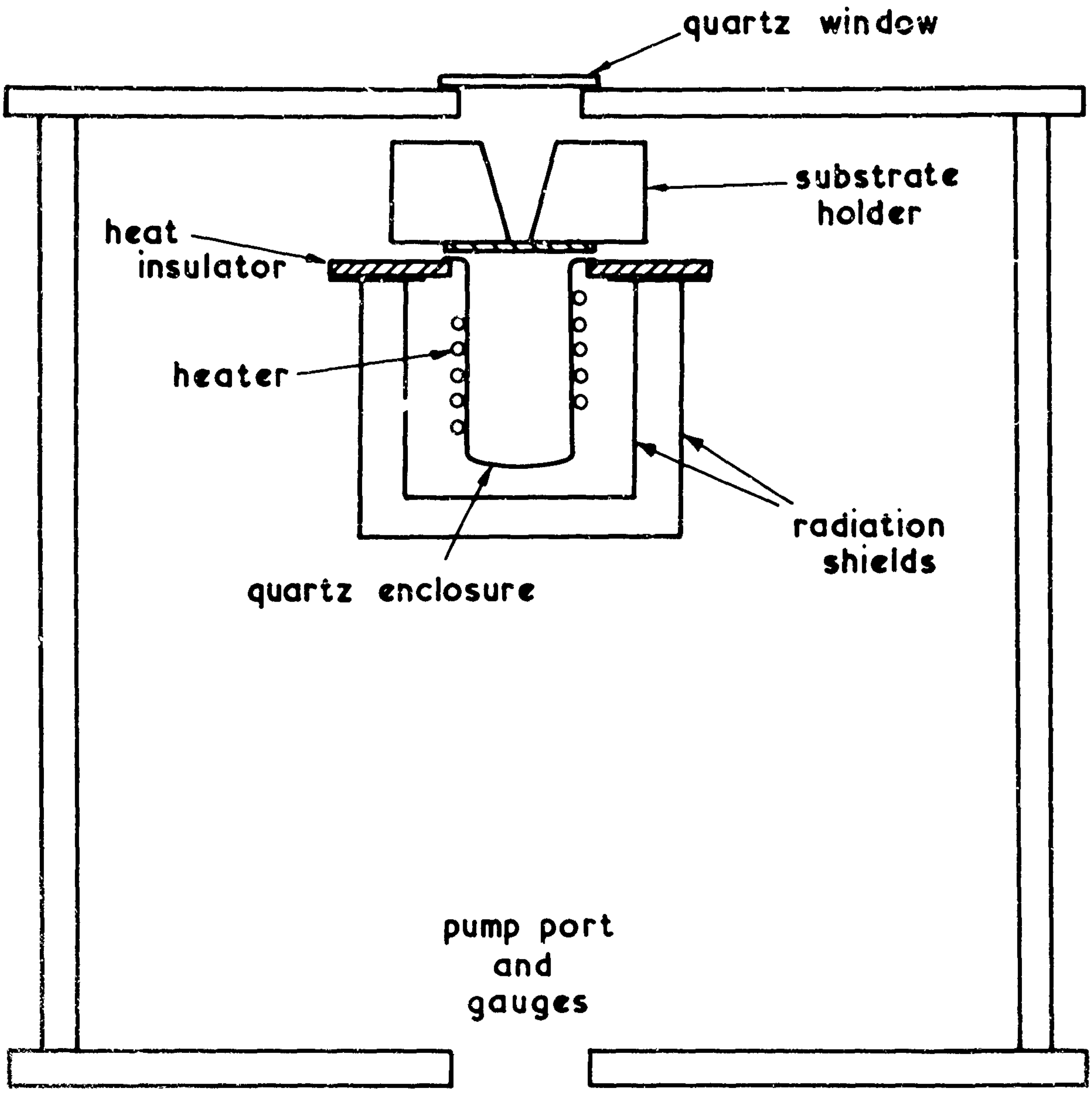


FIG. 3·16

GAS FLOW METHOD

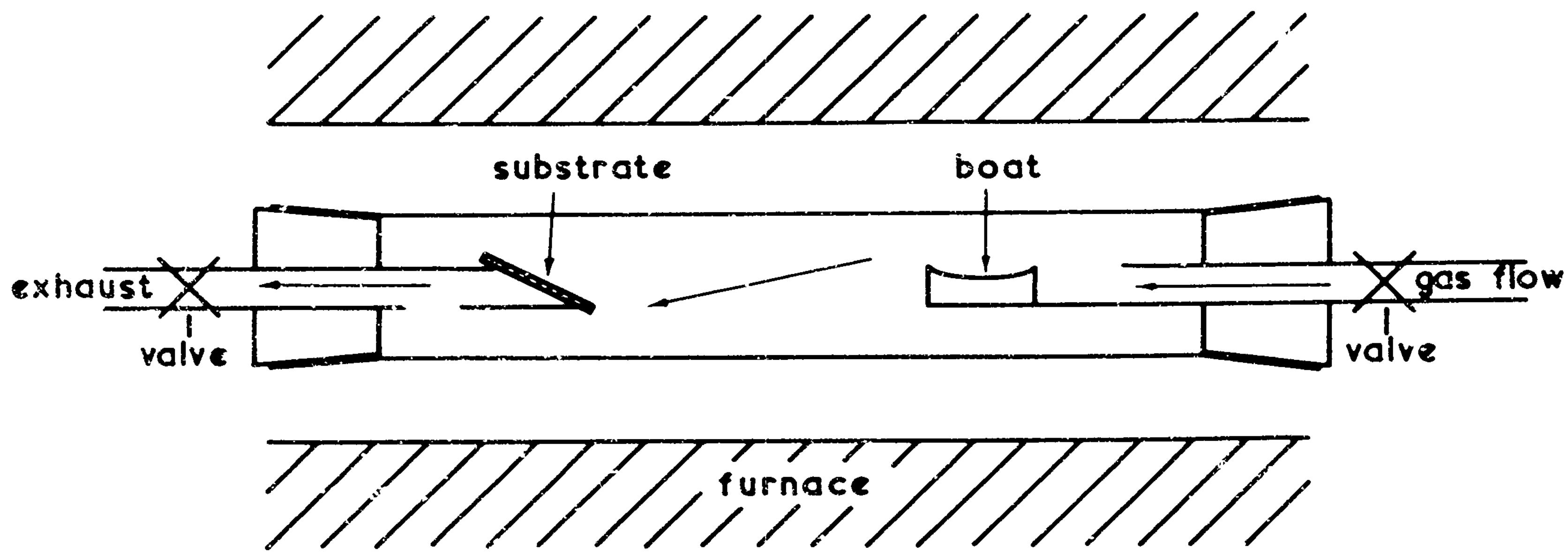


FIG. 3.17

COMPARISON OF GROUND AND POLISHED SILICON SUBSTRATES

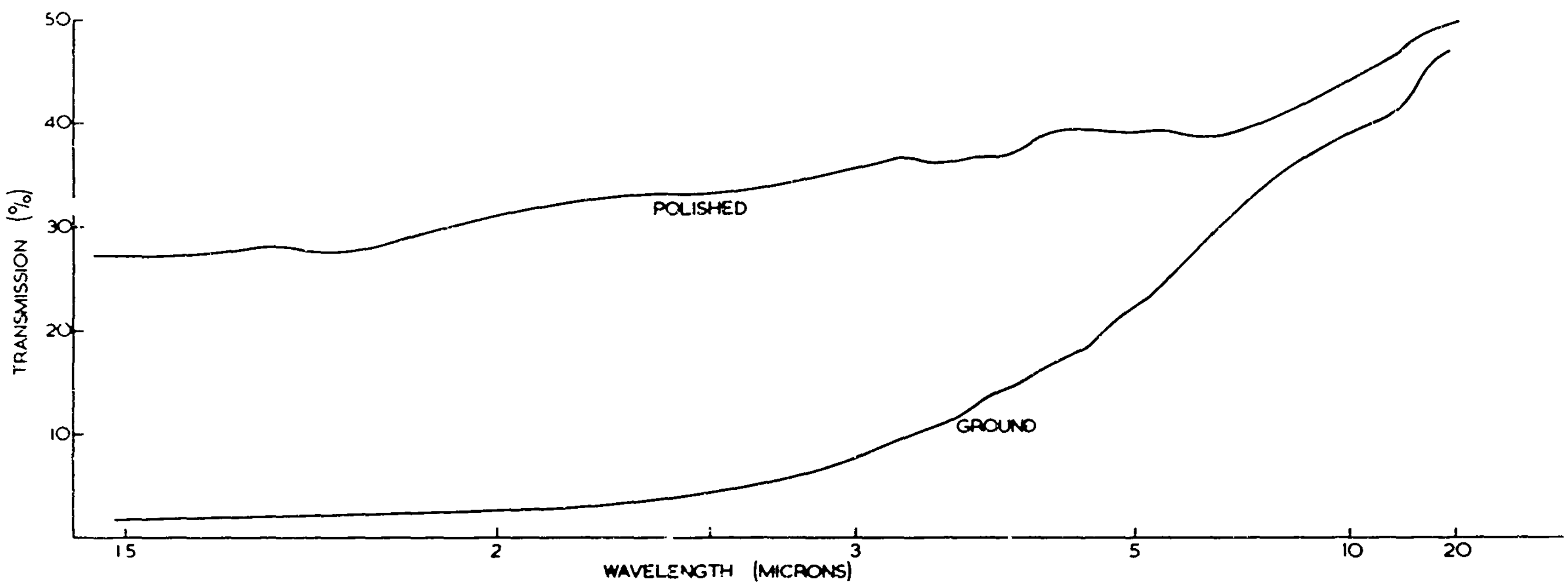


FIG 3.18

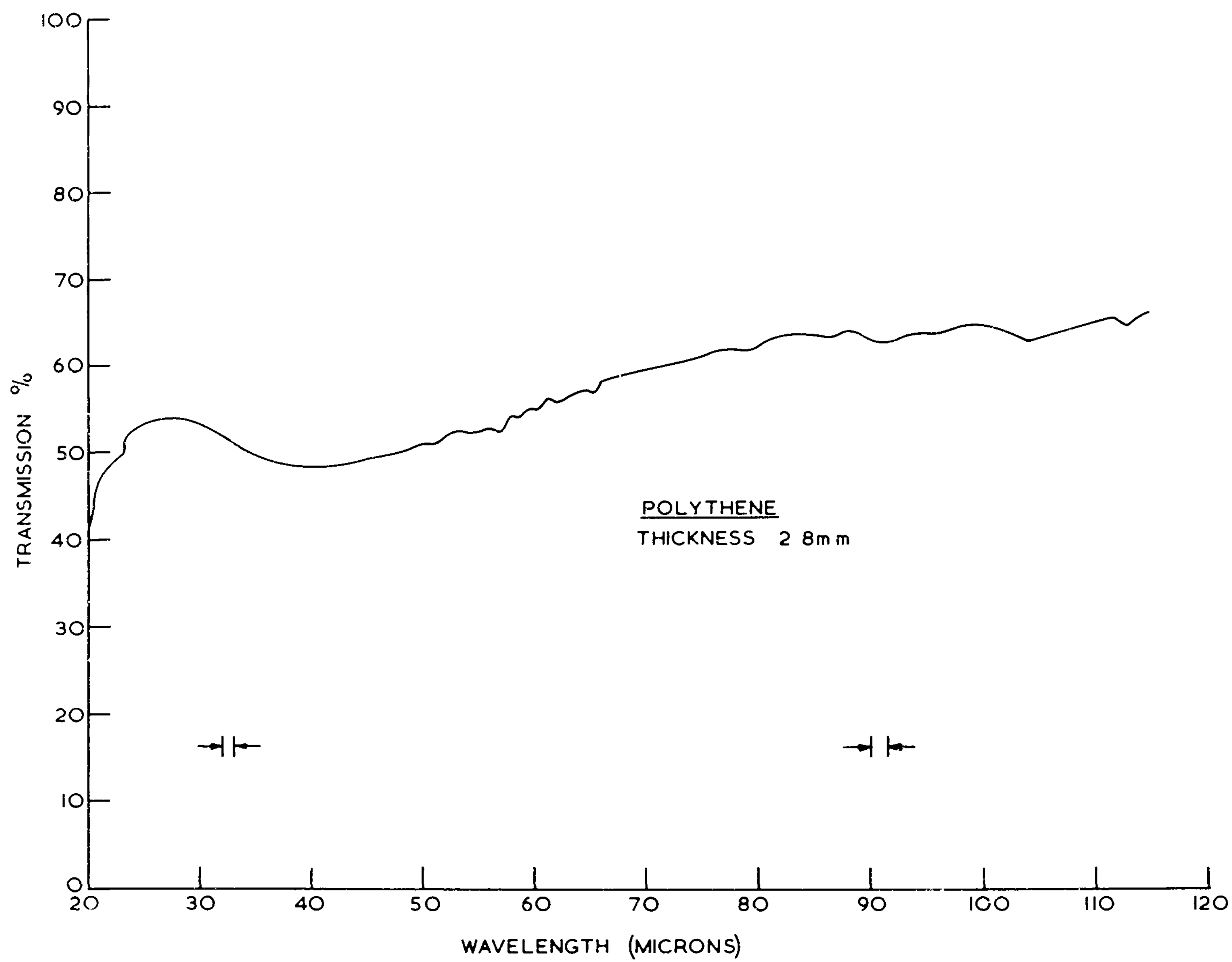
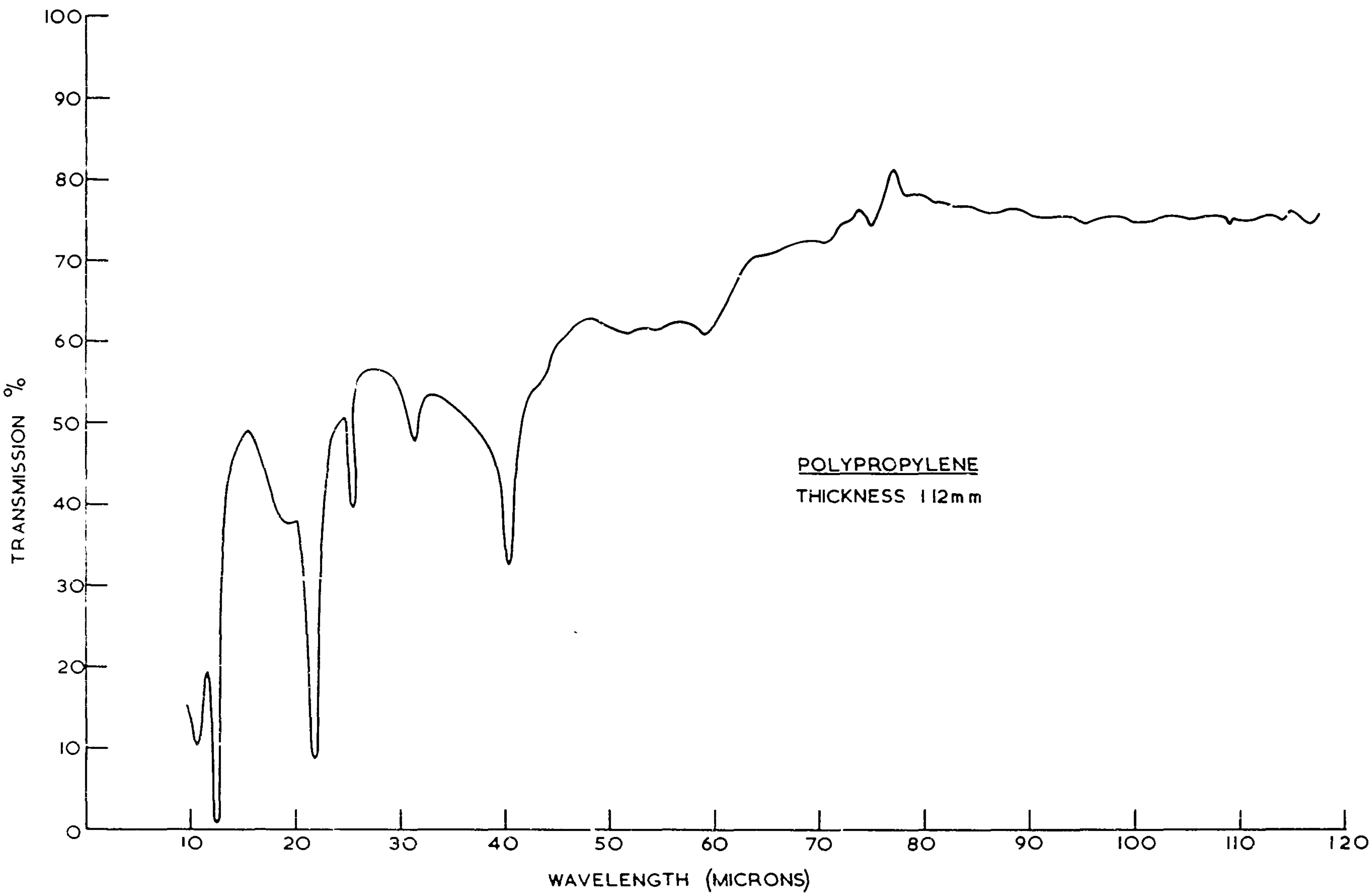

TRANSMISSION %
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)
POLYTHENE
THICKNESS 2 8mm

FIG 3.19



100
90
80
70
60
50
40
30
20
10
0
TRANSMISSION %
10
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)
POLYPROPYLENE
THICKNESS 1.12mm

FIG. 3.20

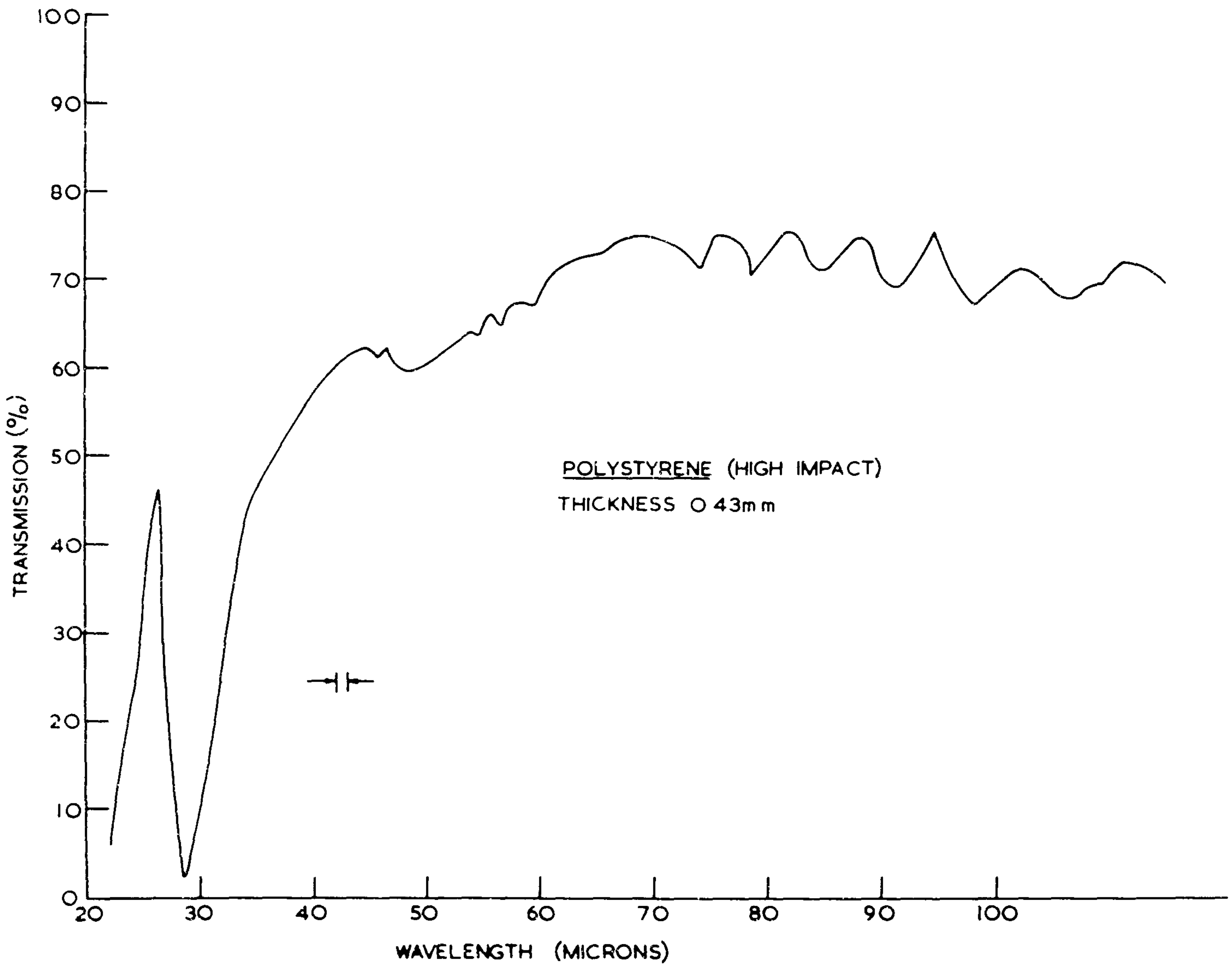
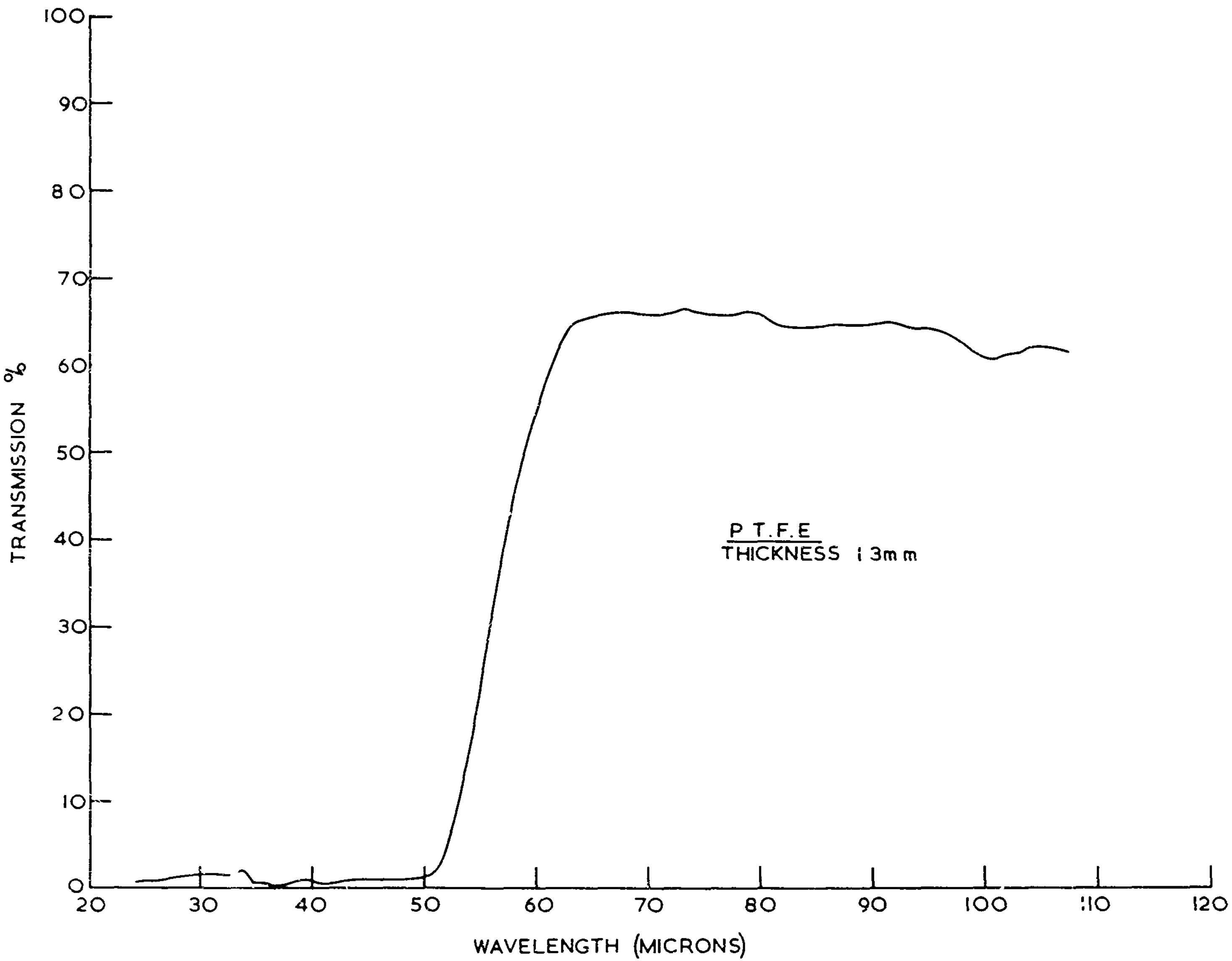
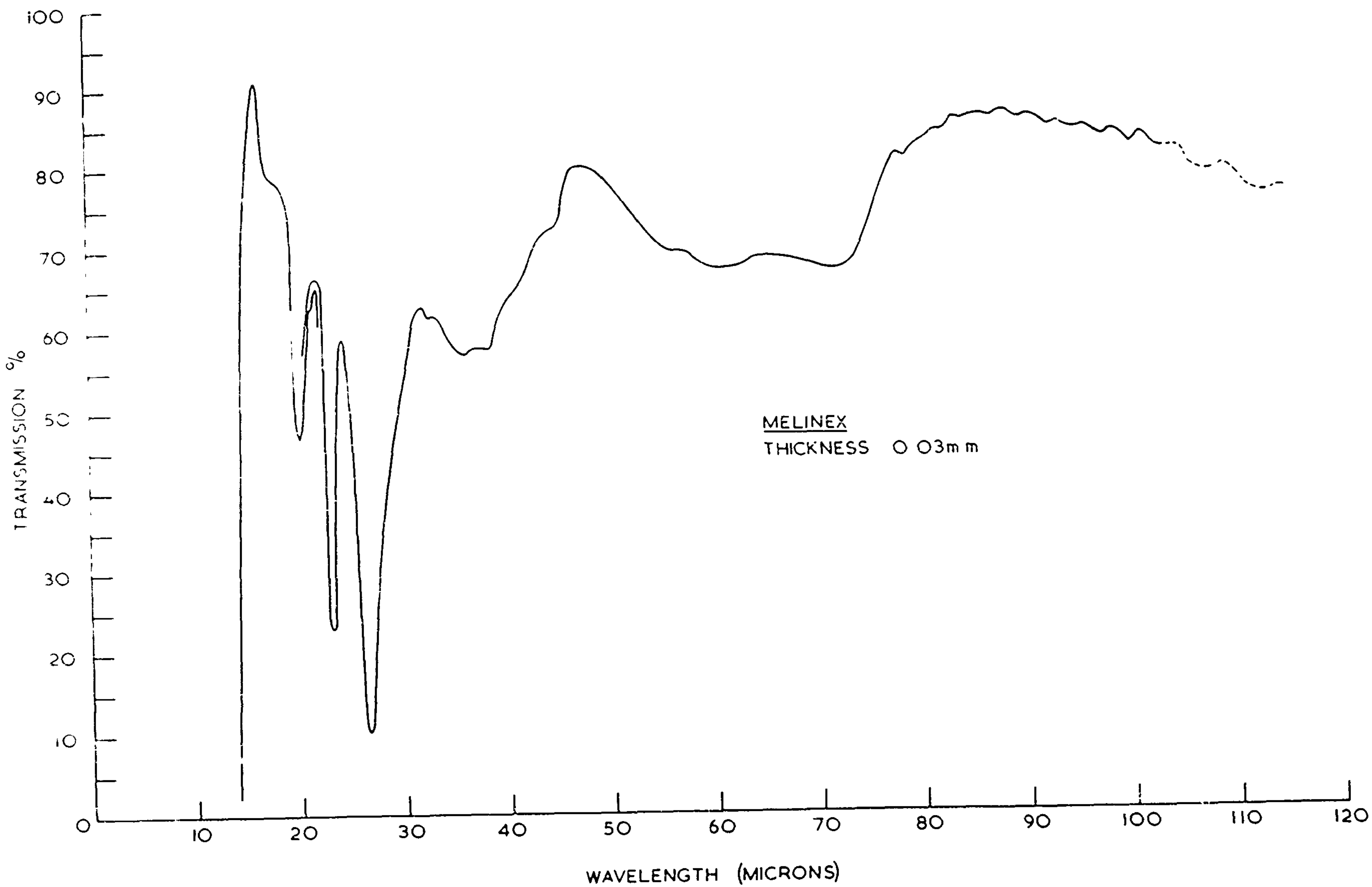

100
90
80
70
60
50
40
30
20
10
0
TRANSMISSION (%)
20
30
40
50
60
70
80
90
100
WAVELENGTH (MICRONS)
POLYSTYRENE (HIGH IMPACT)
THICKNESS 0 43mm

FIG. 3.21



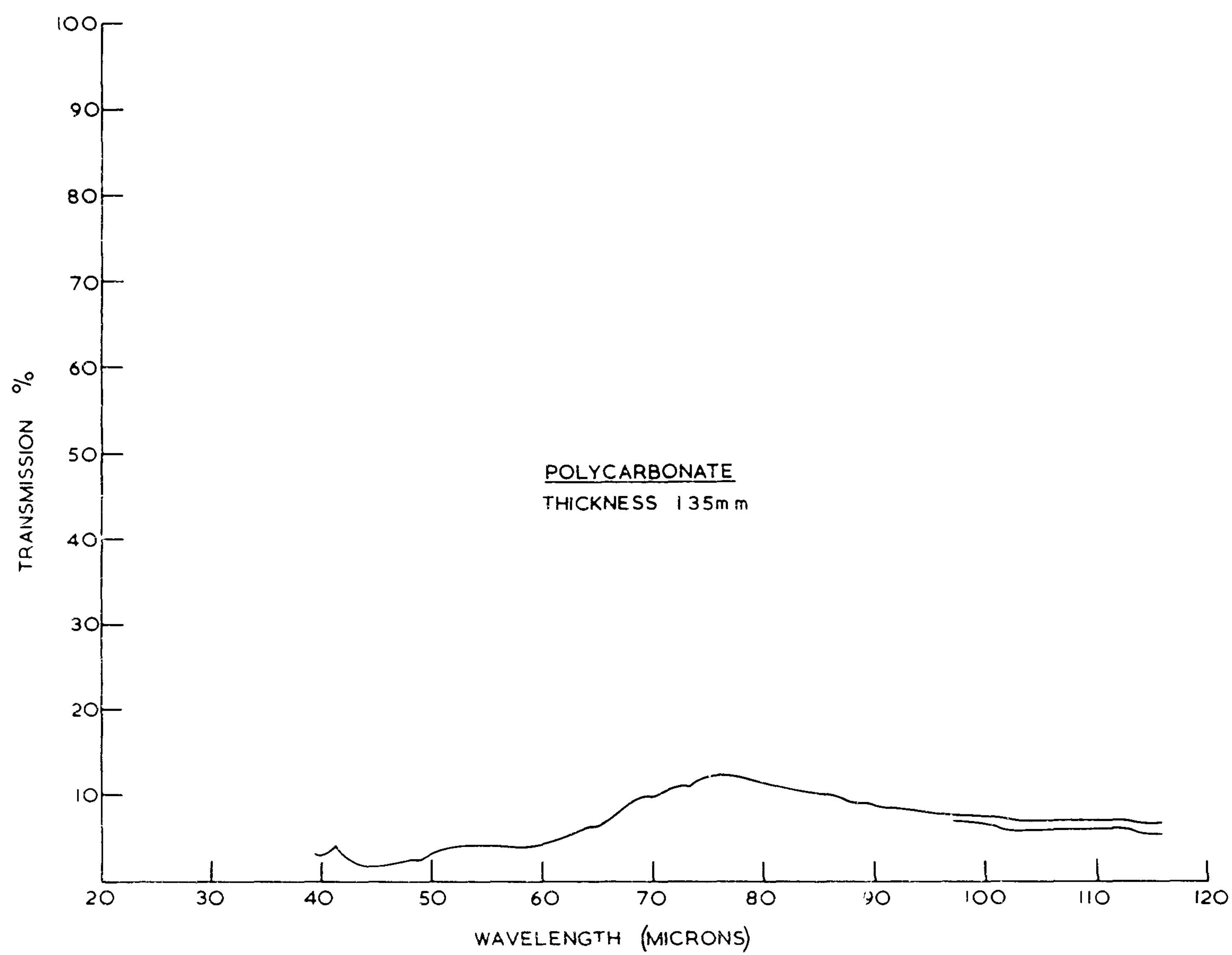
TRANSMISSION %
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)
P T.F.E
THICKNESS 1 3mm

FIG 3.22



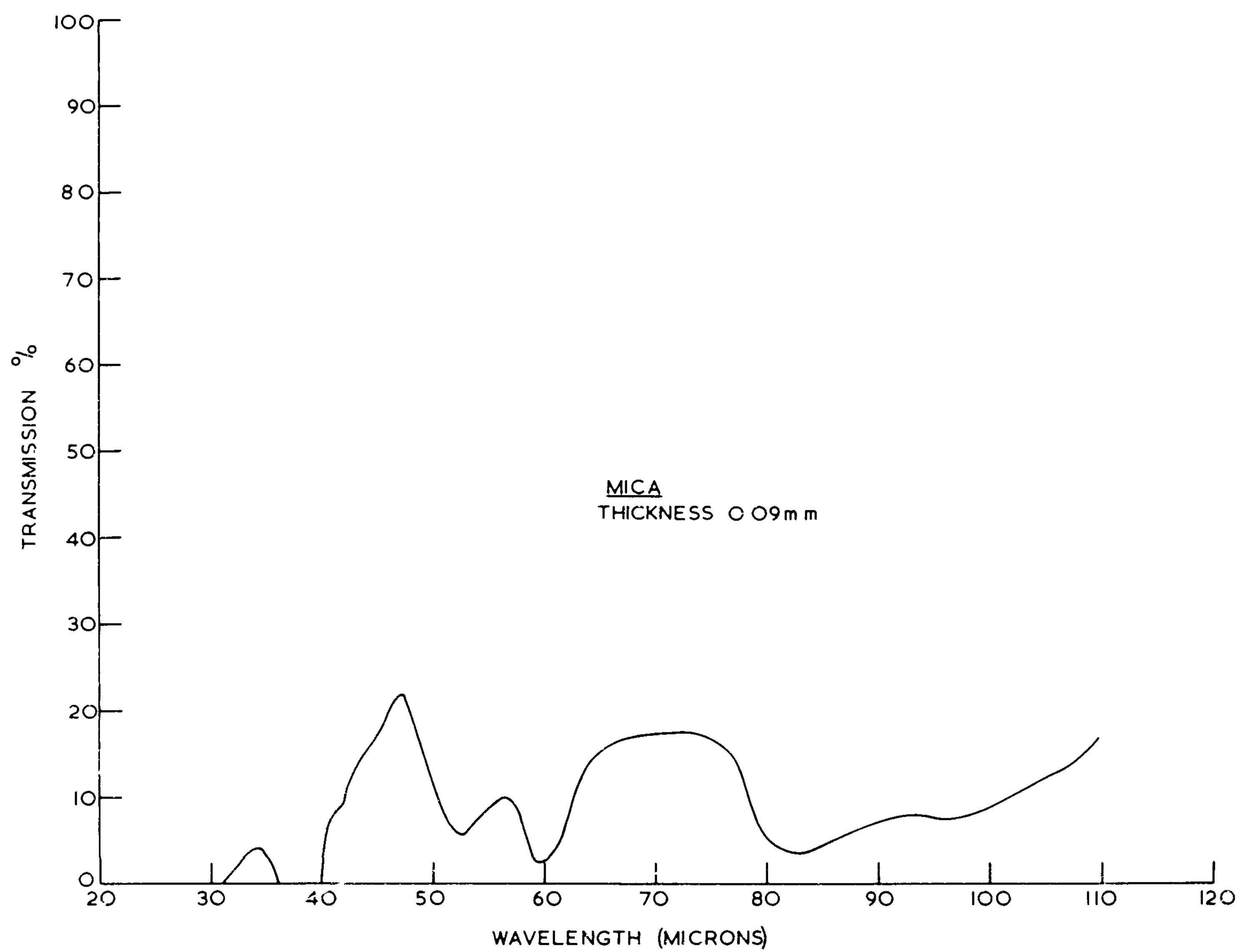
100
90
80
70
60
50
40
30
20
10
0
TRANSMISSION %
10
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)
MELINEX
THICKNESS 0 03mm

FIG. 3.23



100
90
80
70
60
50
40
30
20
10
TRANSMISSION %
POLYCARBONATE
THICKNESS 1 35mm
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)

FIG 3 24



MICA
THICKNESS 0 09mm
TRANSMISSION %
100
90
80
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
90
100
110
120
WAVELENGTH (MICRONS)

FIG 3 25

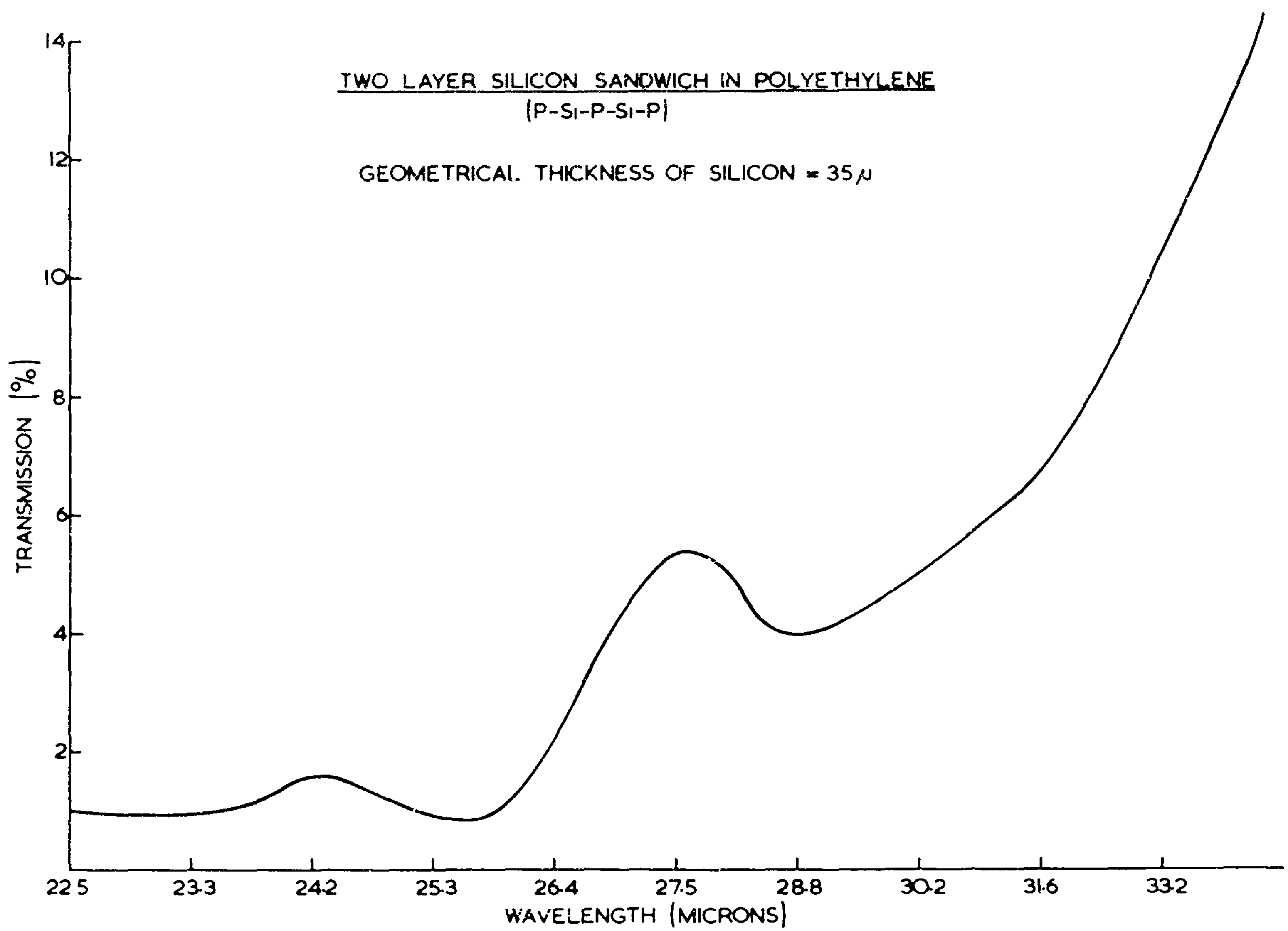

TWO LAYER SILICON SANDWICH IN POLYETHYLENE
(P-Si-P-Si-P)
GEOMETRICAL THICKNESS OF SILICON = 35 μ
TRANSMISSION (%)
14
12
10
8
6
4
2
22.5
23.3
24.2
25.3
26.4
27.5
28.8
30.2
31.6
33.2
WAVELENGTH (MICRONS)

FIG 3.26

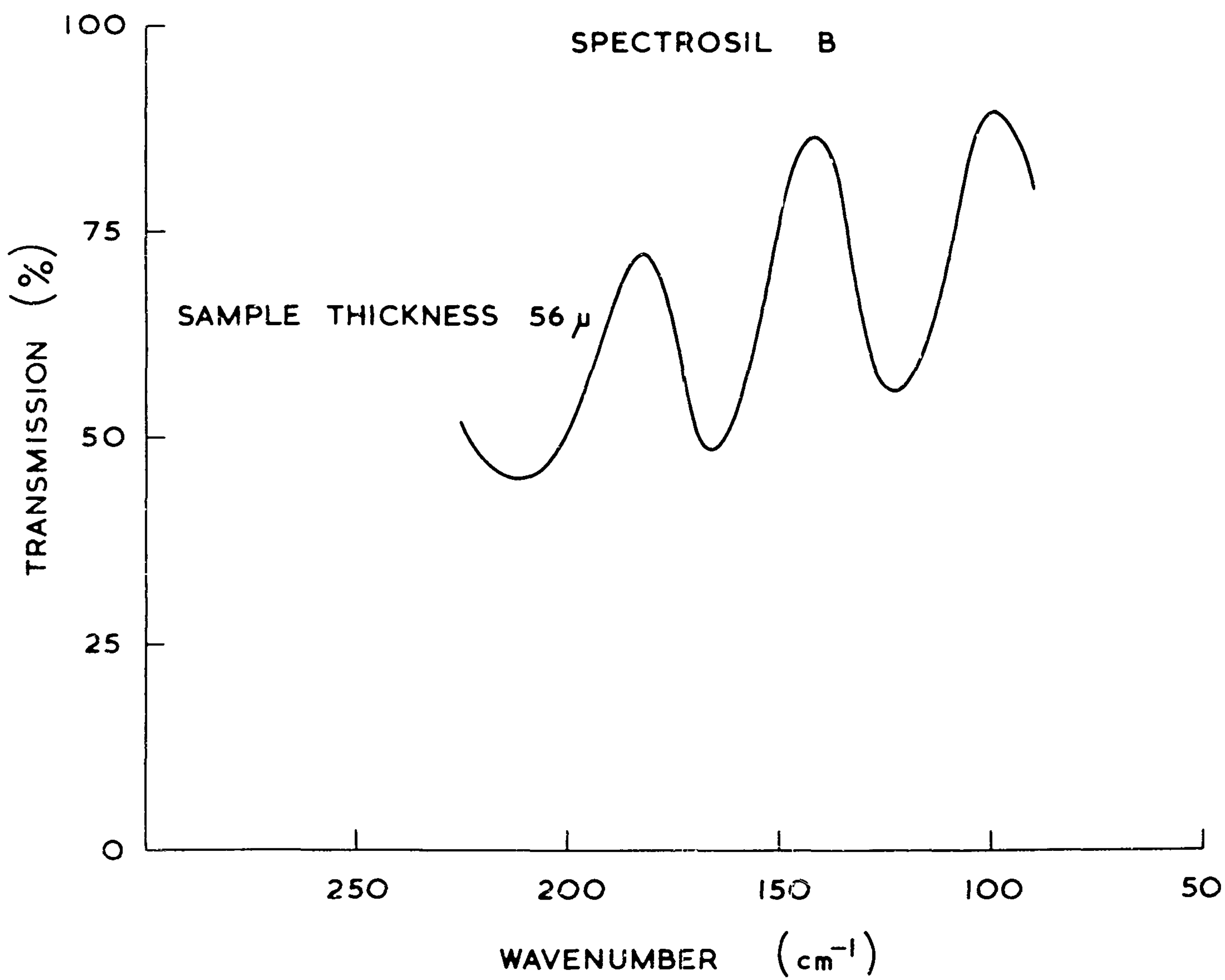

SPECTROSIL B
SAMPLE THICKNESS 56 μ
TRANSMISSION (%)
100
75
50
25
0
250
200
150
100
50
WAVENUMBER (cm⁻¹)

FIG. 3·27

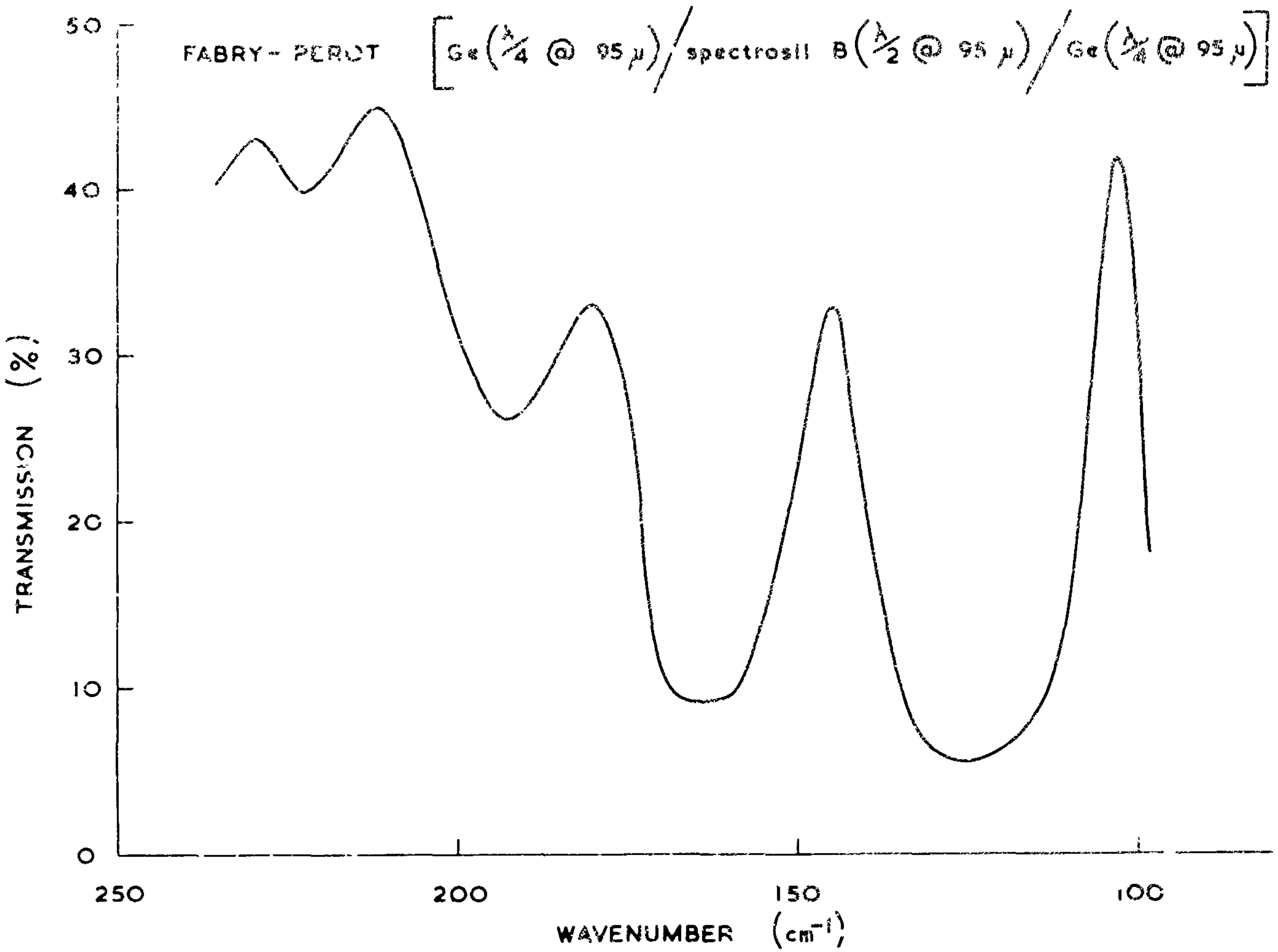

FABRY - PEROT
[Ge(λ/4 @ 95 μ)/spectrosil B(λ/2 @ 95 μ)/Ge(λ/4 @ 95 μ)]
50
40
30
20
10
0
TRANSMISSION (%)
250
200
150
100
WAVENUMBER (cm⁻¹)

FIG 3.28

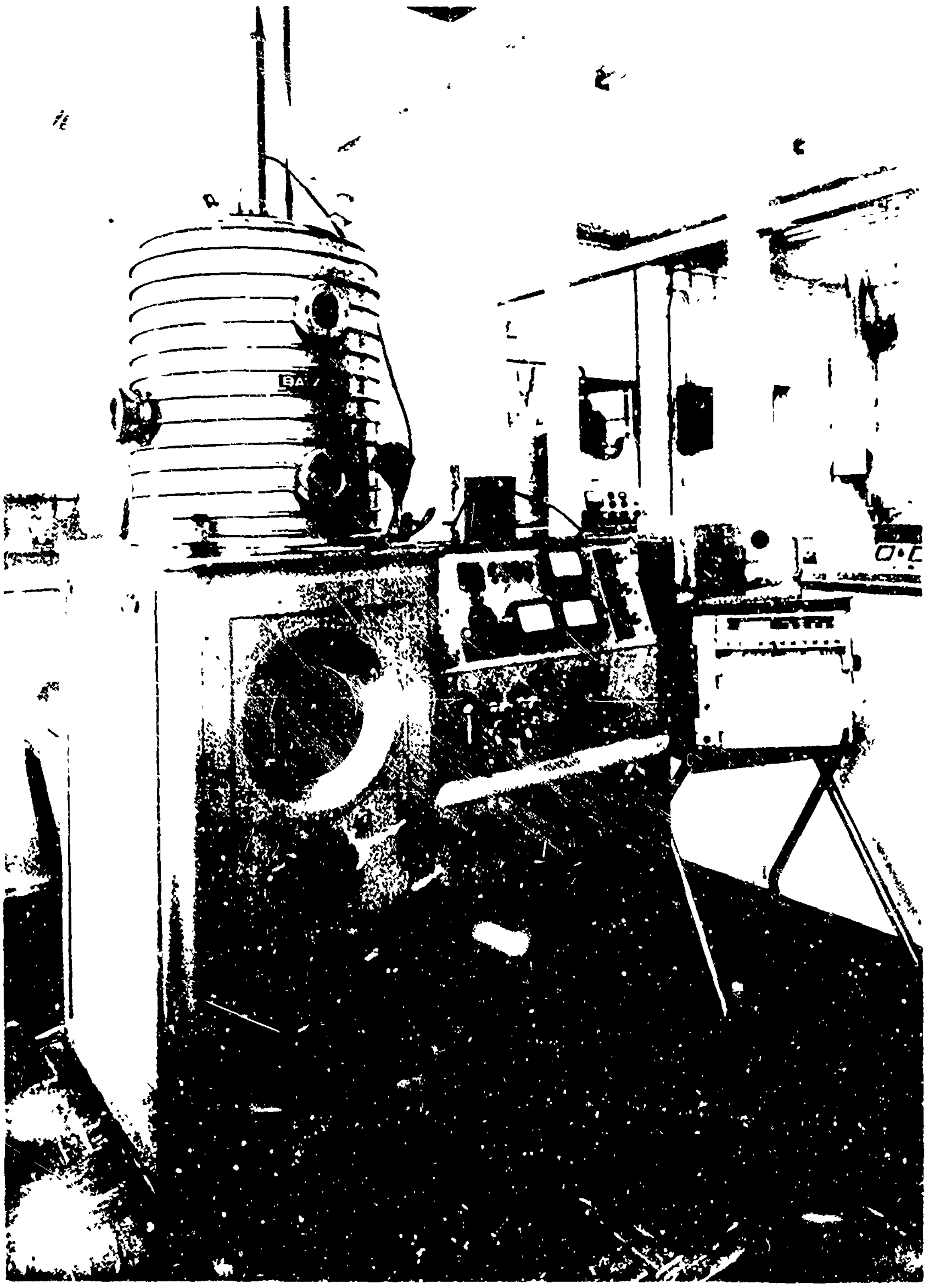
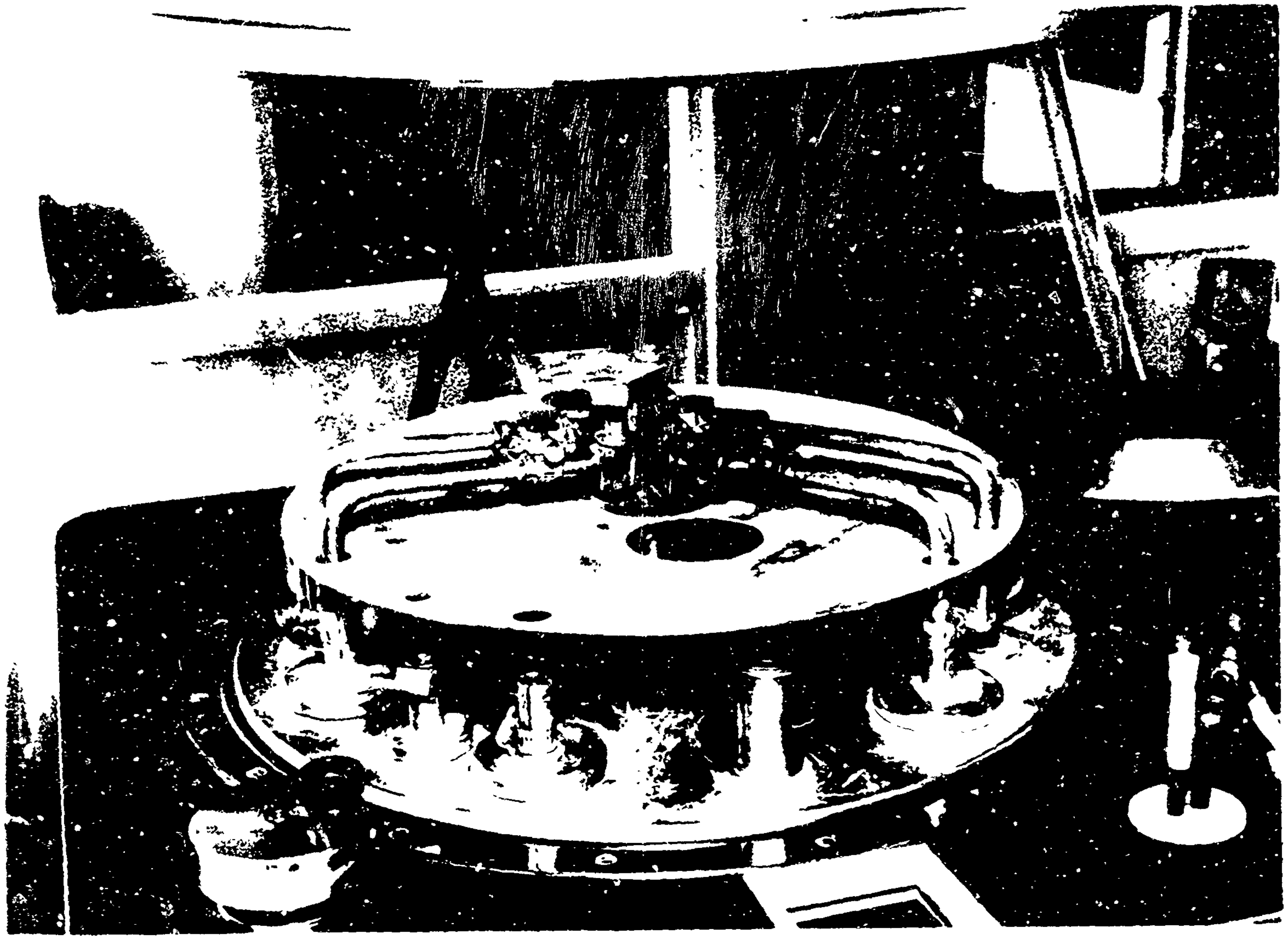


FIG: 4.1(a) B A 500 PLANT USED at GRUBB PARSONS

FIG: 4.1 (b) ARRANGEMENT of FIXED SOURCES



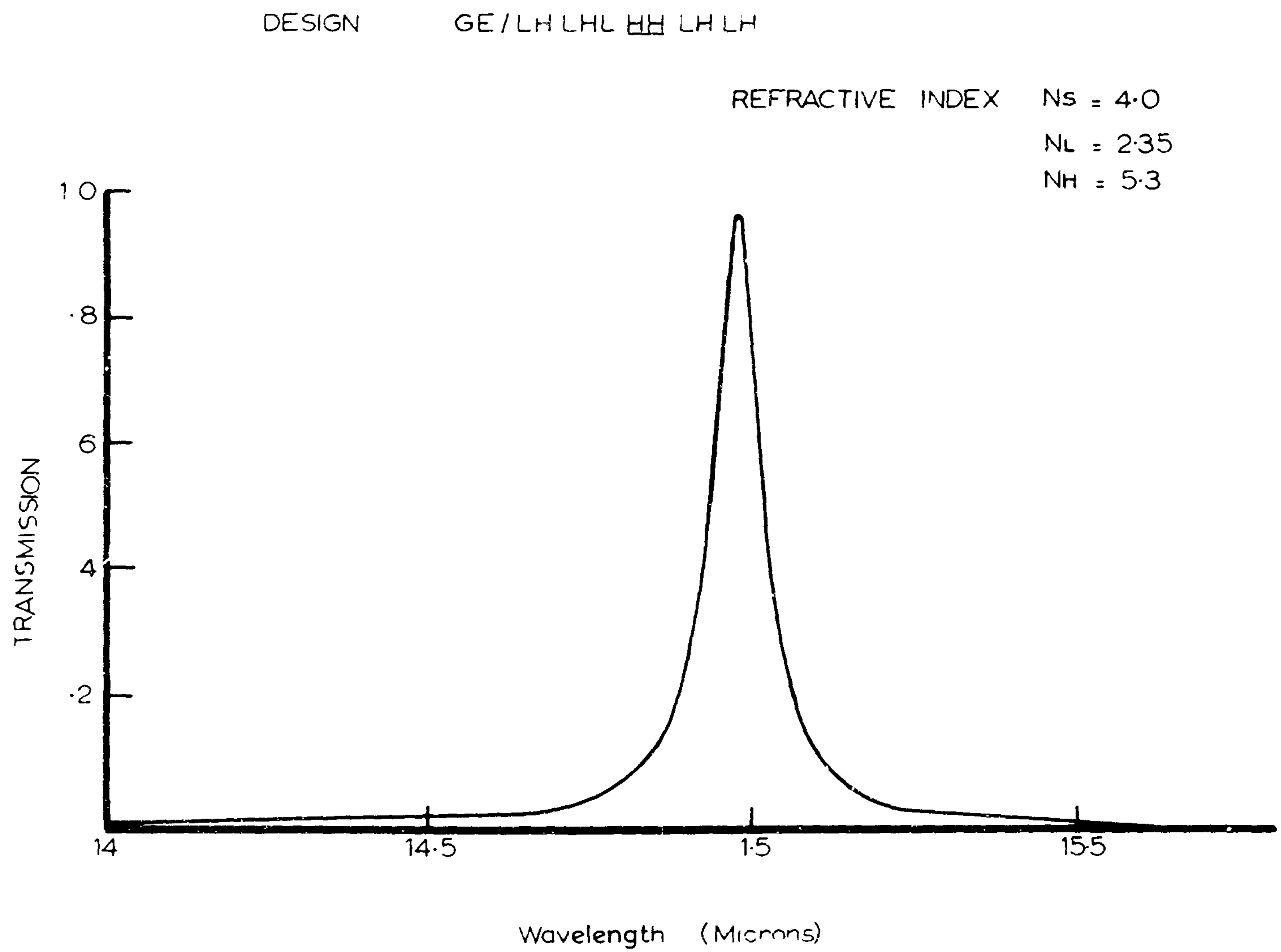


FIG 4. 2 (a) COMPUTED TRANSMISSION OF FABRY PEROT AT 15μ

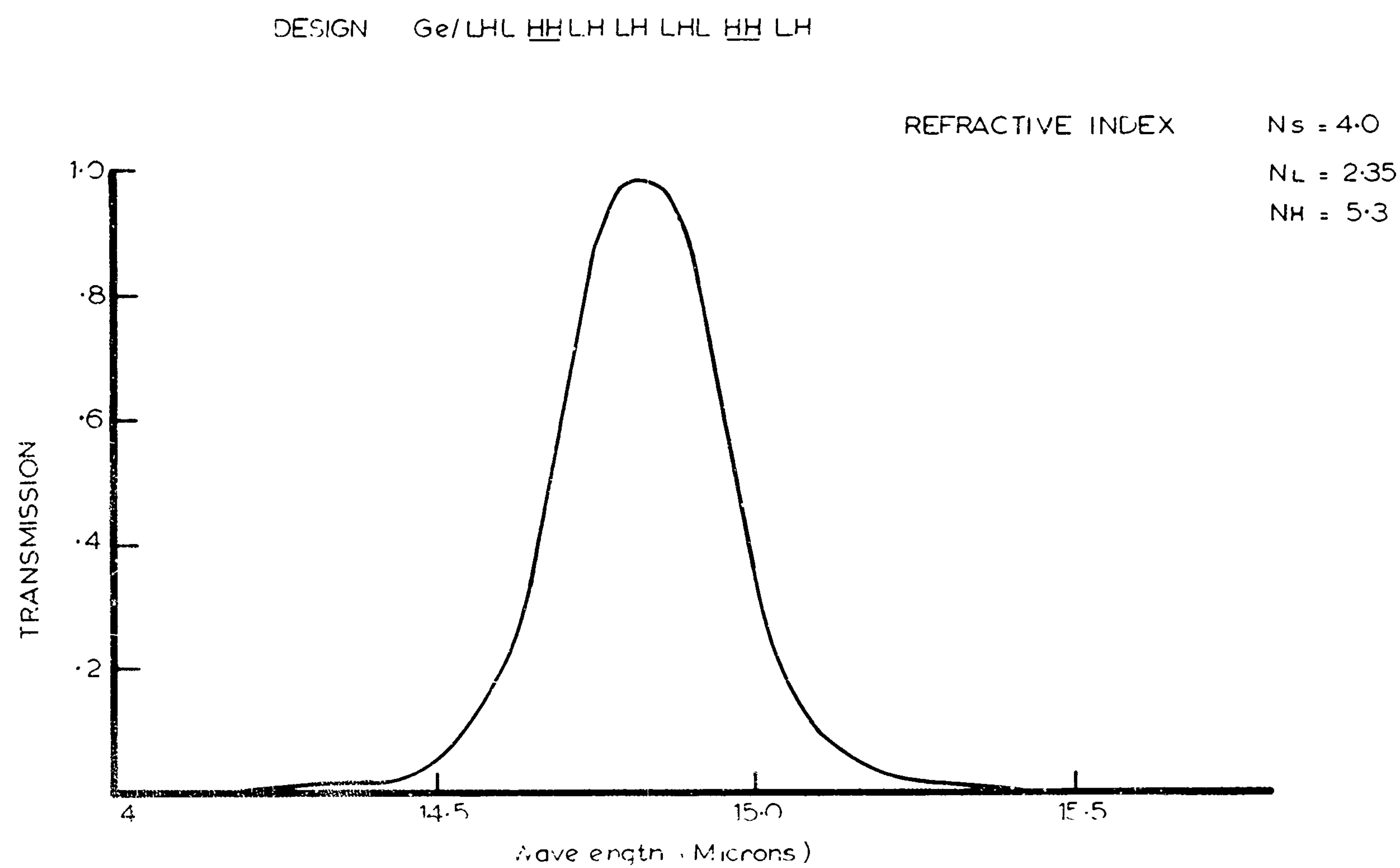


FIG 4.2 (b) COMPUTED TRANSMISSION OF D.H.W. AT 14·83μ

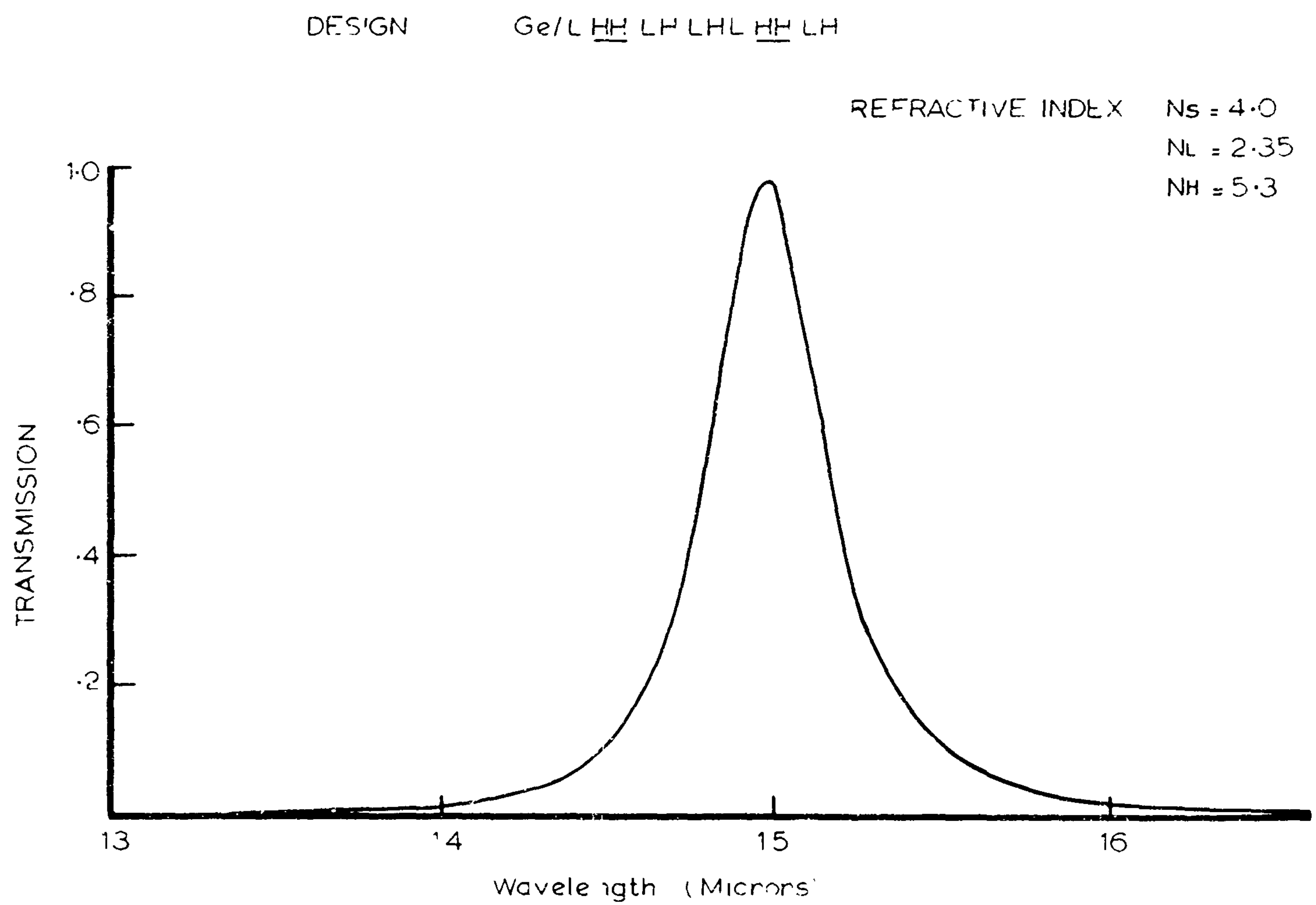
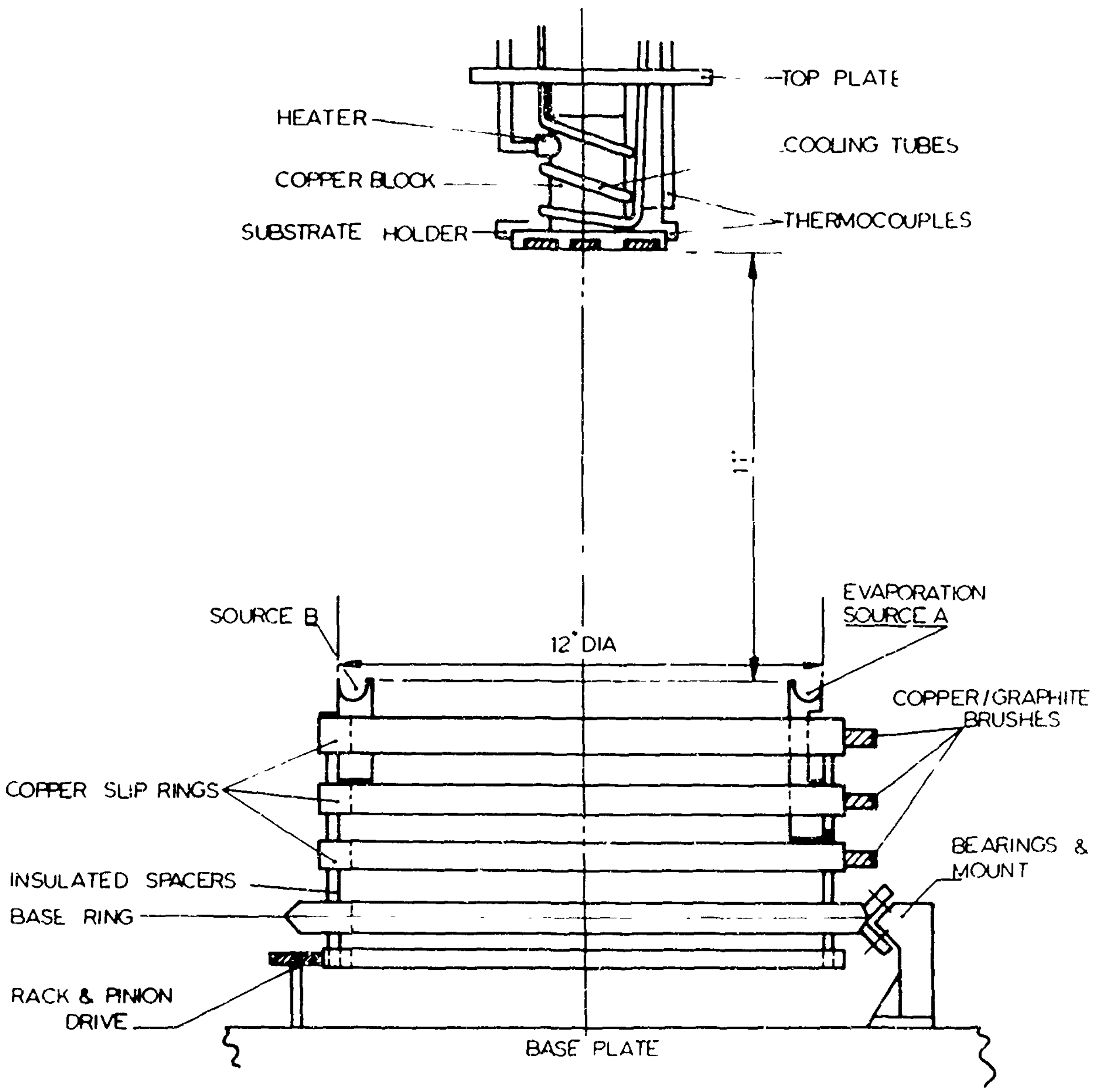


FIG 4.2 (C) COMPUTED TRANSMISSION OF D.H.W. AT 15μ



SCHEMATIC DIAGRAM OF ROTATING SOURCE ASSEMBLY & SUBSTRATE HOLDER

FIG 4.3

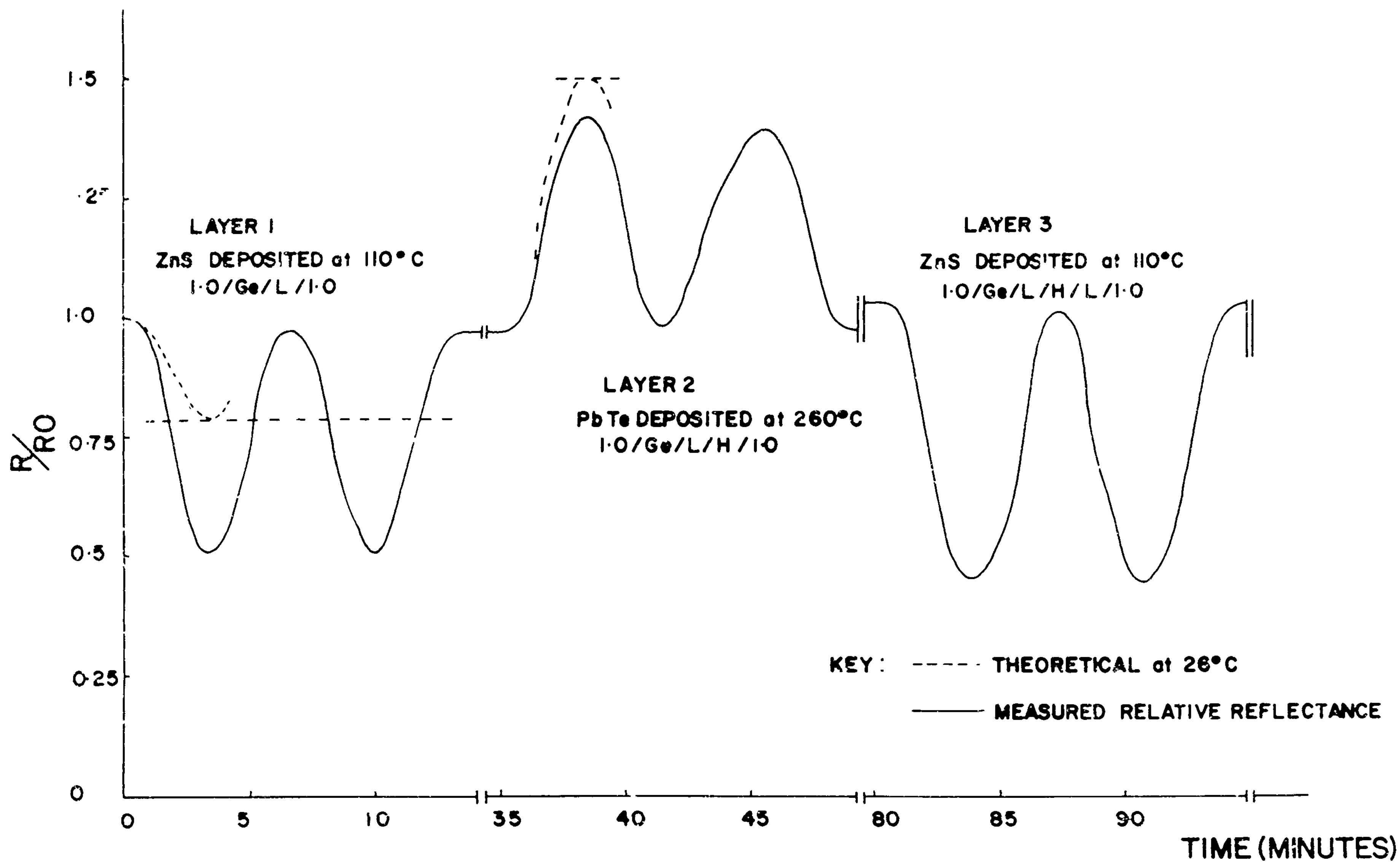


FIG 4·4 REFLECTANCE MONITORING in the 4th ORDER SCHEMATIC

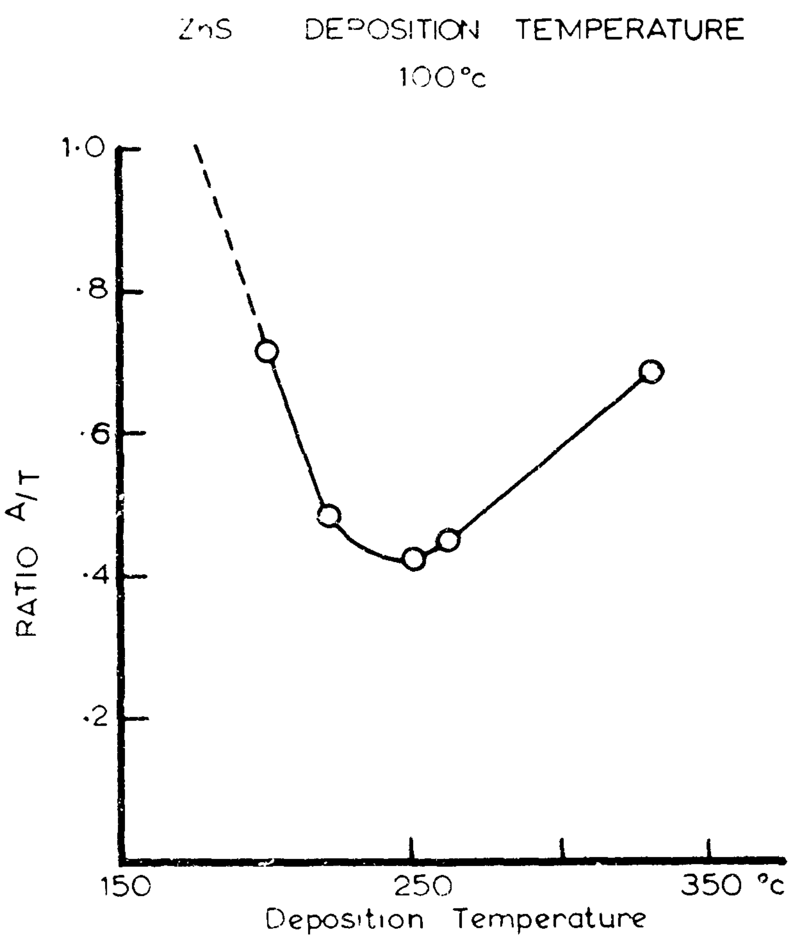


FIG 4.5 (a) VARIATION IN FABRY PEROT ABSORPTION WITH PbTe DEPOSITION TEMPERATURE.

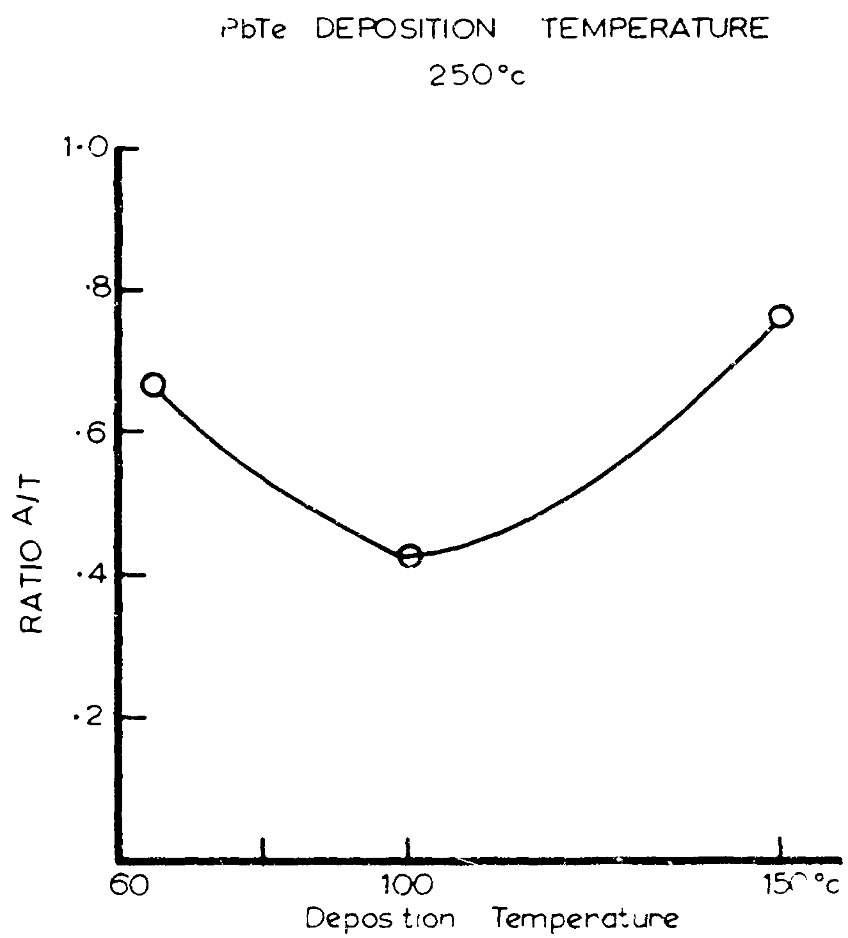


FIG 4.5 (b) VARIATION IN FABRY PEROT ABSORPTION WITH ZnS DEPOSITION TEMPERATURE.

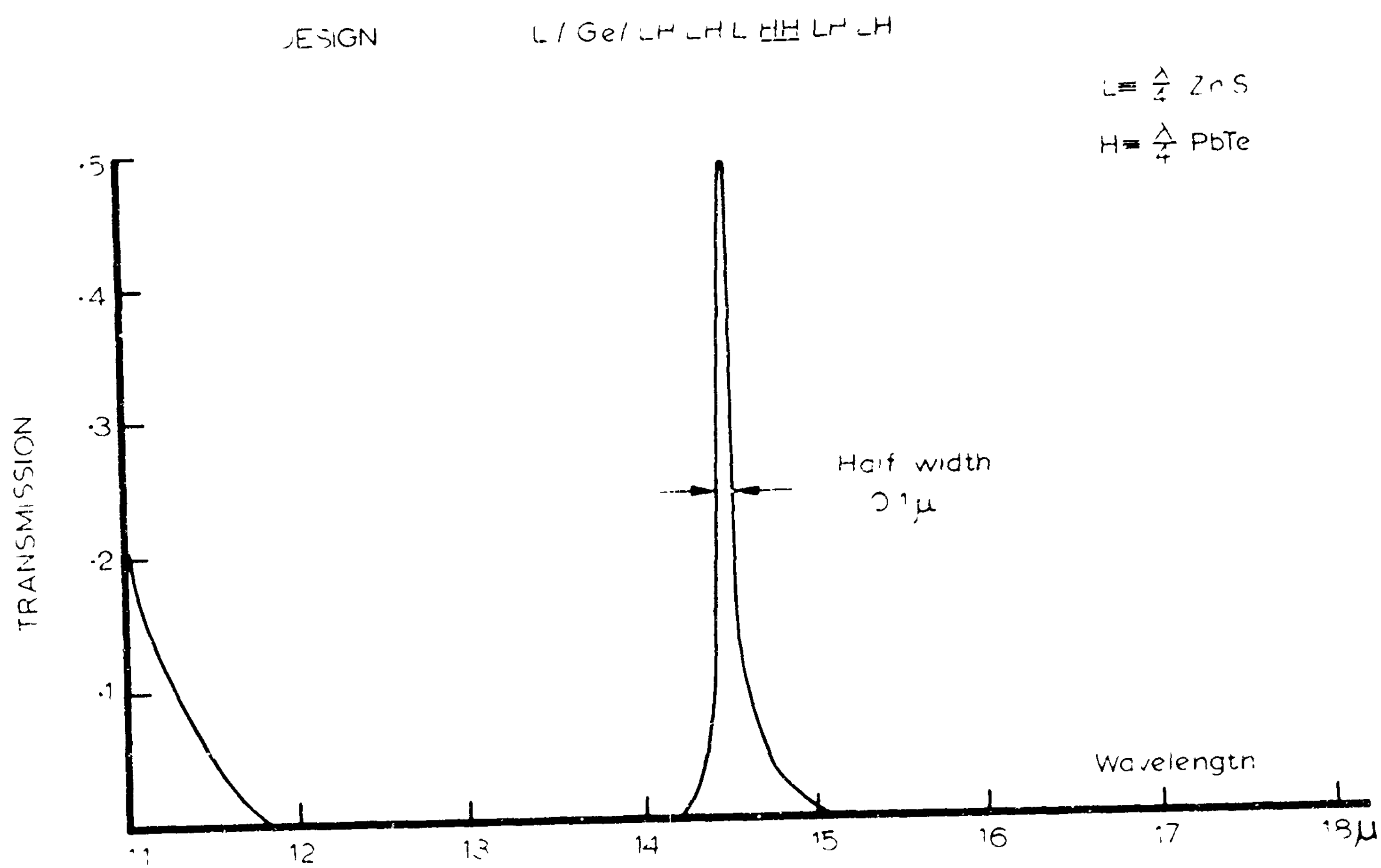


FIG 4.6. MEASURED TRANSMISSION OF FABRY PEROT D18

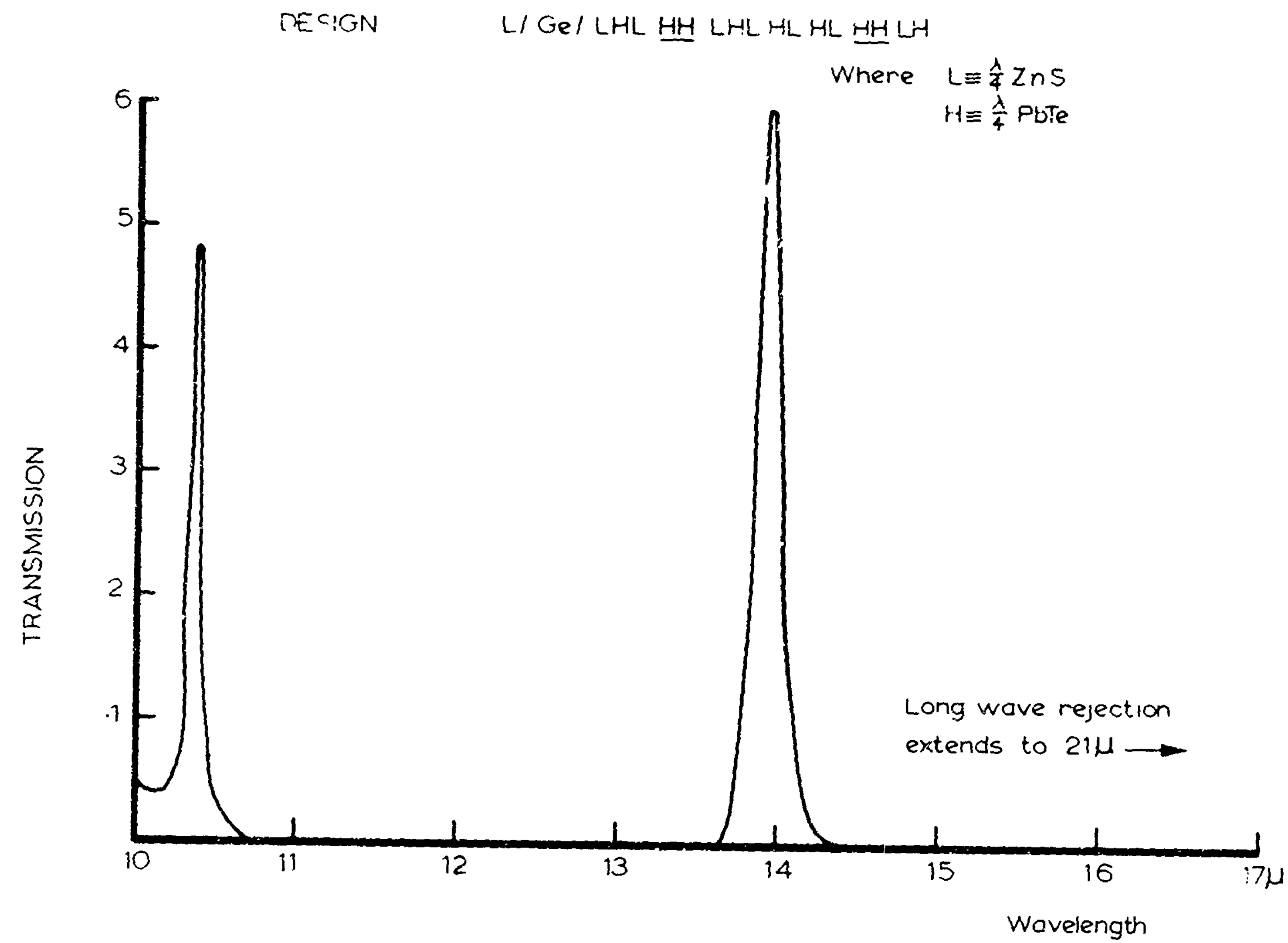


FIG. 4.7(a) MEASURED TRANSMISSION OF D.H.W.5.

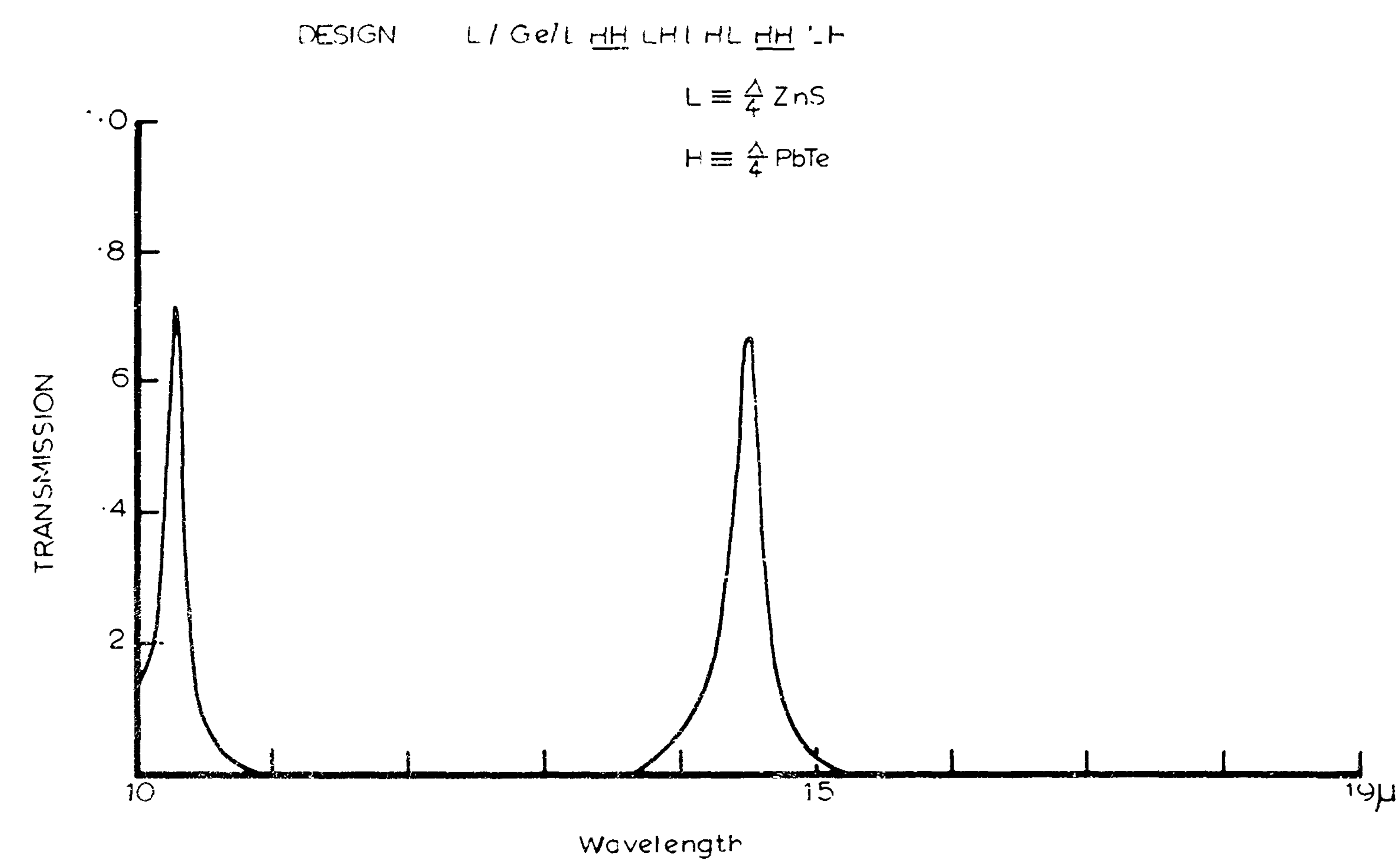


FIG 4.7 (b) MEASURED TRANSMISSION OF D.H.W. 13.

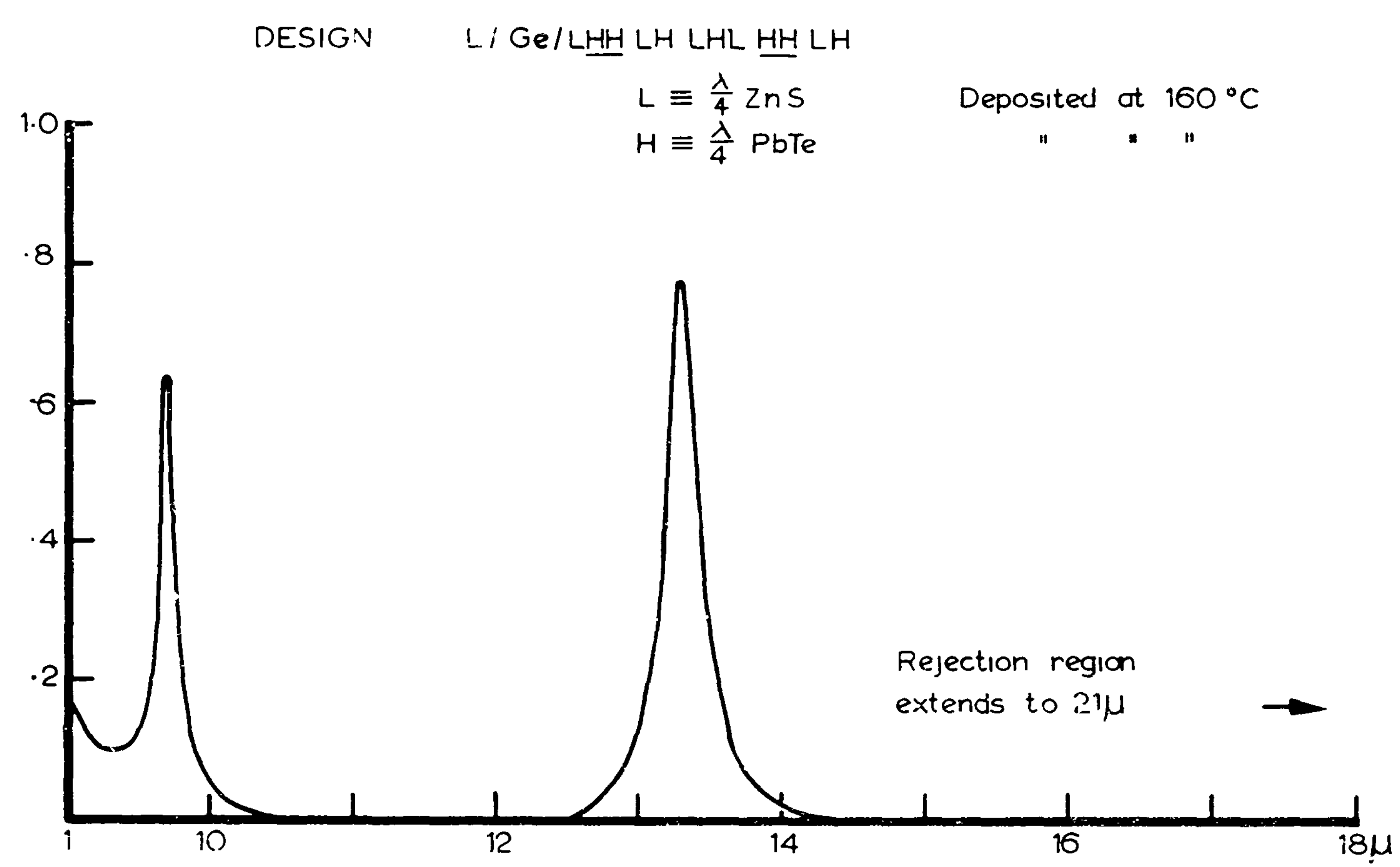
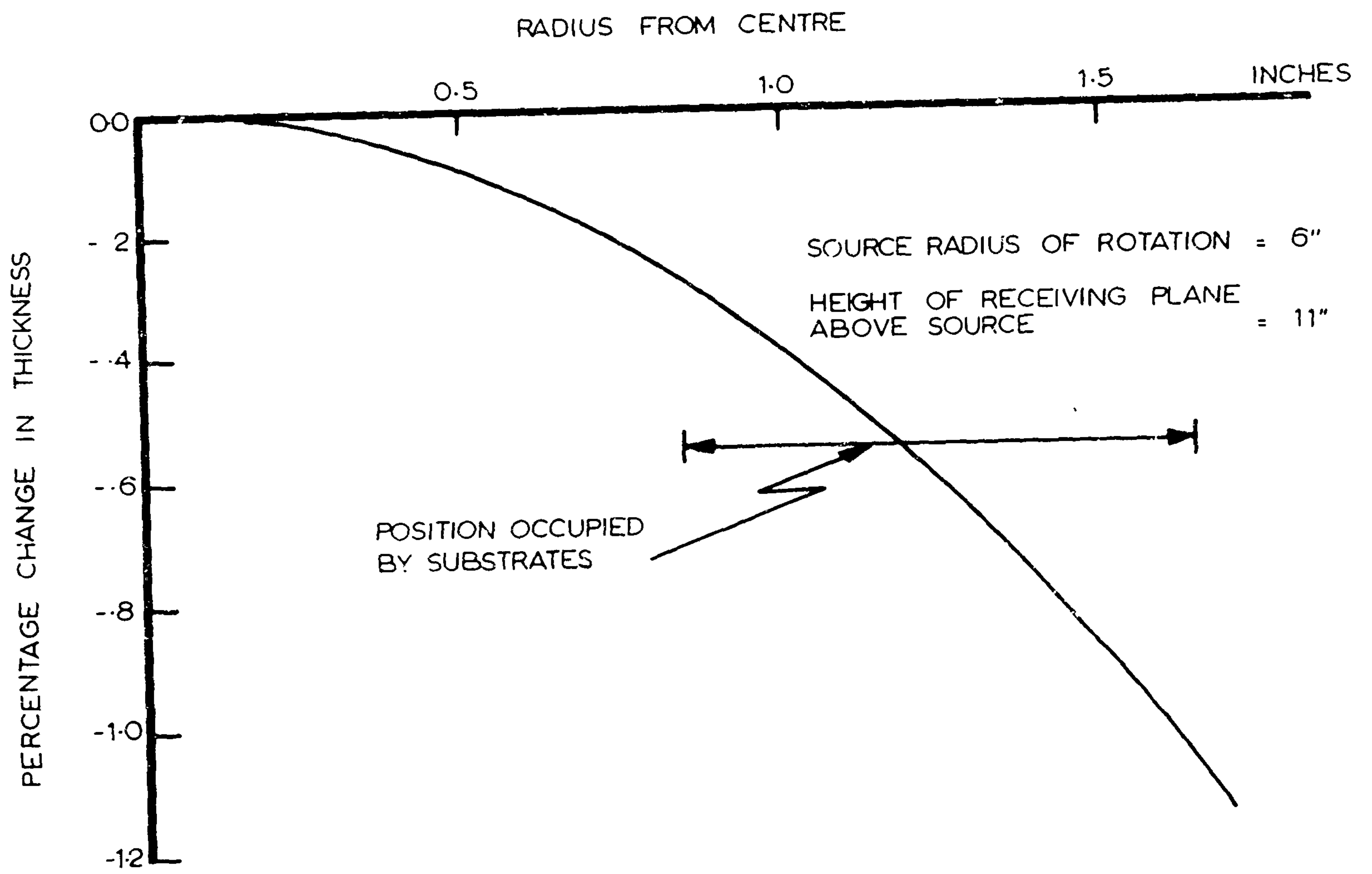


FIG. 4.8. MEASURED TRANSMISSION OF D.H.W.19.

FIG .4.9. THEORETICAL DISTRIBUTION OF EVAPORANT FROM A SMALL ROTATING SURFACE SOURCE.



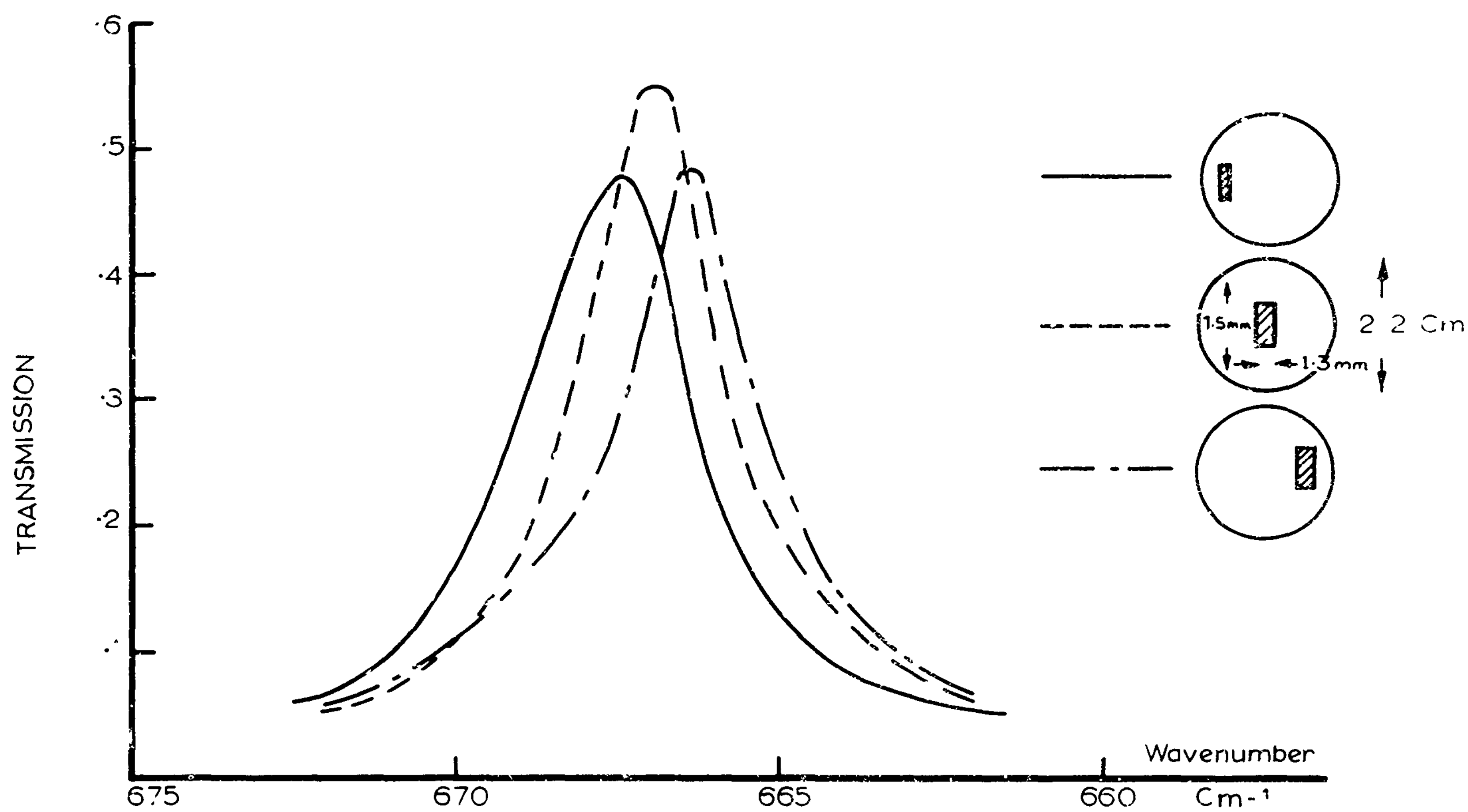


FIG. 4.10 F.P. FILTER 8180/4/MONITOR. MEASUREMENTS TAKEN AT 3 DIFFERENT PLACES ON FILTER SURFACE AT A FOCUS POSITION & AT NORMAL INCIDENCE.

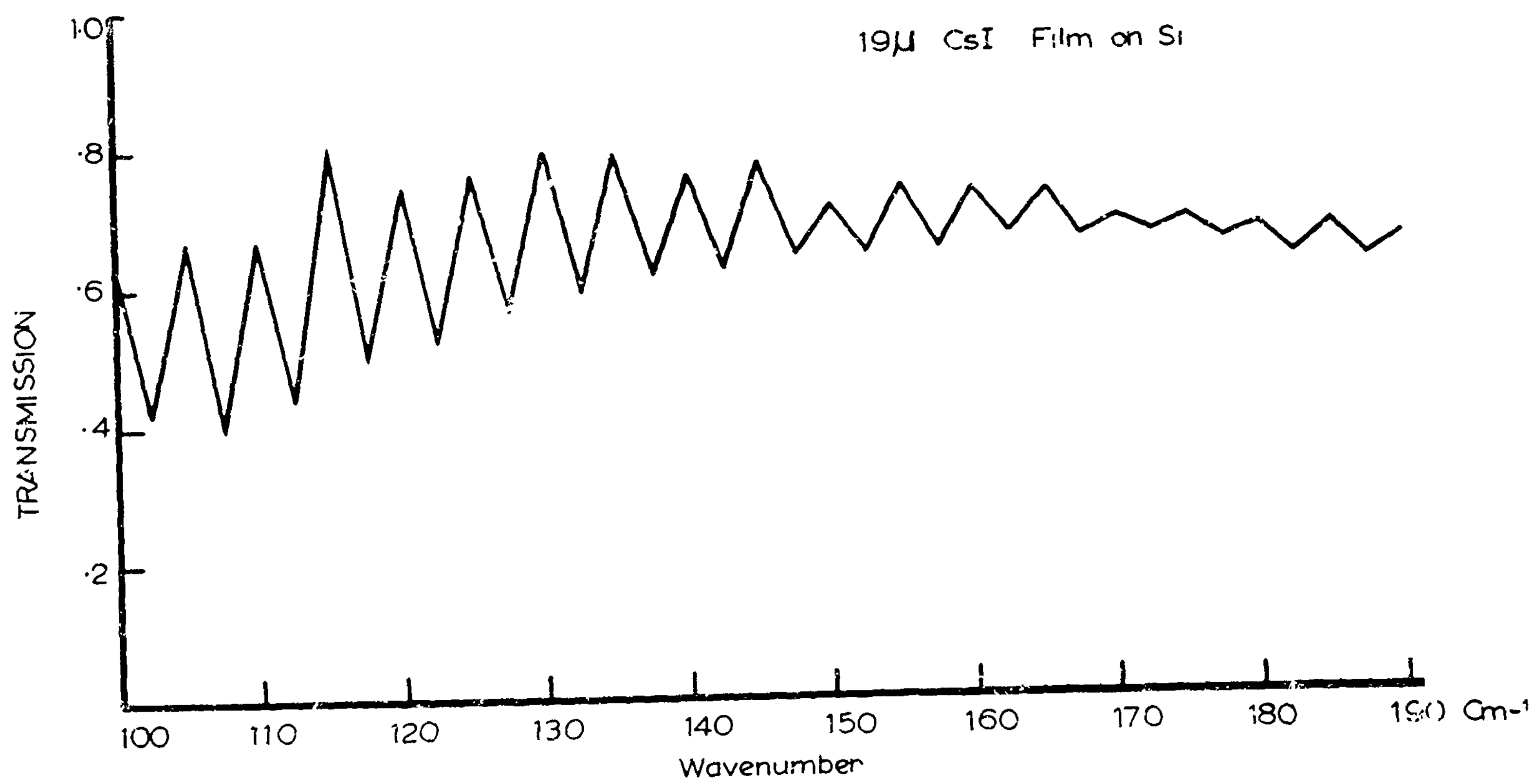


FIG.4.11. INTERFEROMETRIC MEASUREMENT OF A CsI FILM ON Si SUBSTRATE AT 2·5 Cm^{-1} RESOLUTION SHOWING FRINGES DUE TO SUBSTRATE INTERFERENCE.

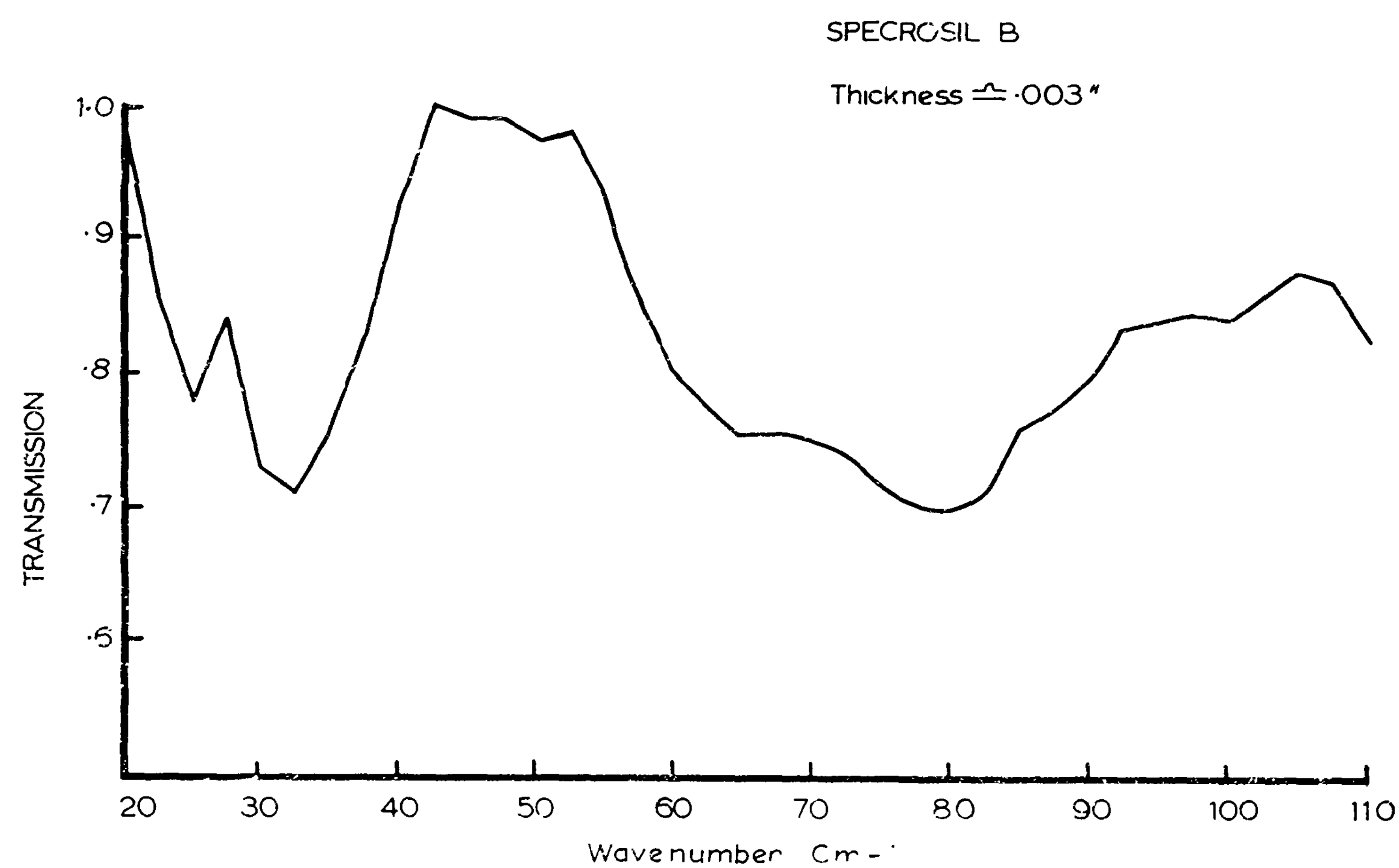
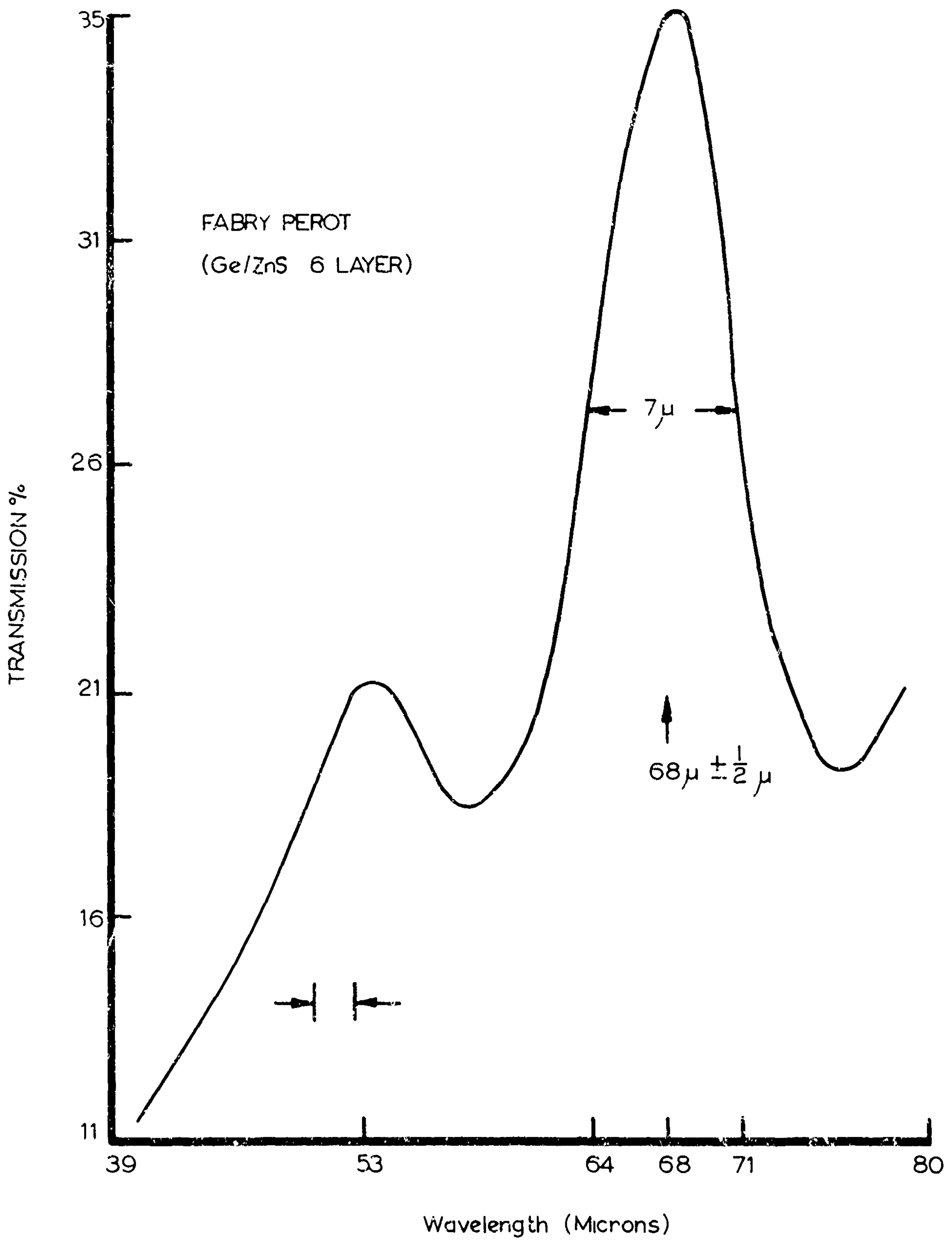


FIG 4.12. TRANSMISSION OF THIN (·003 IN) SPECTROSIL B PLATE AS MEASURED BY IRIS INTERFEROMETER.



FABRY PEROT
(Ge/ZnS 6 LAYER)
TRANSMISSION %
35
31
26
21
16
11
7μ
68μ ± 1/2 μ
39
53
64
68
71
80
Wavelength (Microns)

FIG. 4.13.

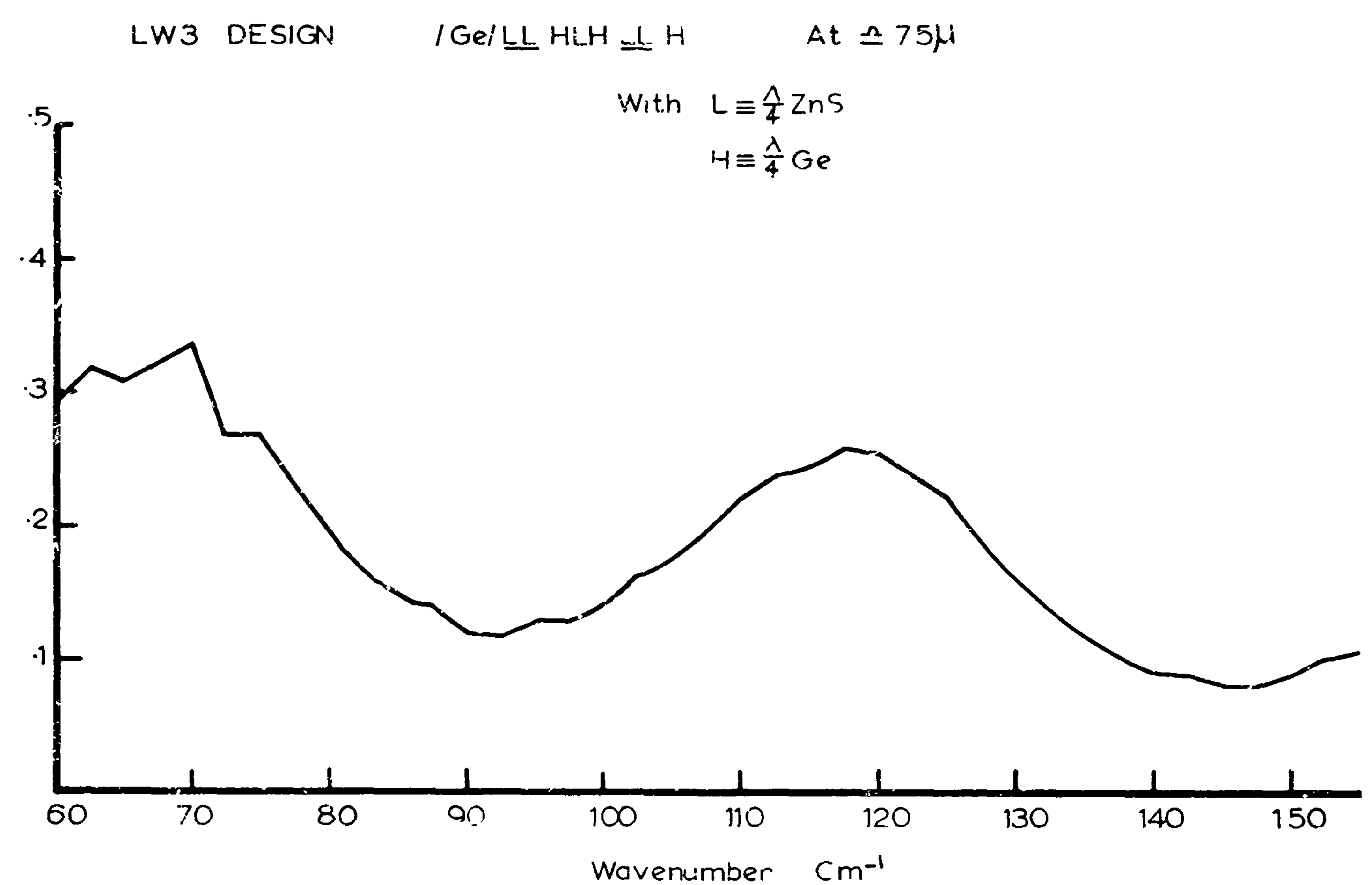


FIG 4.14. MEASURED TRANSMISSION OF FILTER LW3 ON A Ge SUBSTRATE (NOT ANTI-REFLECTED)

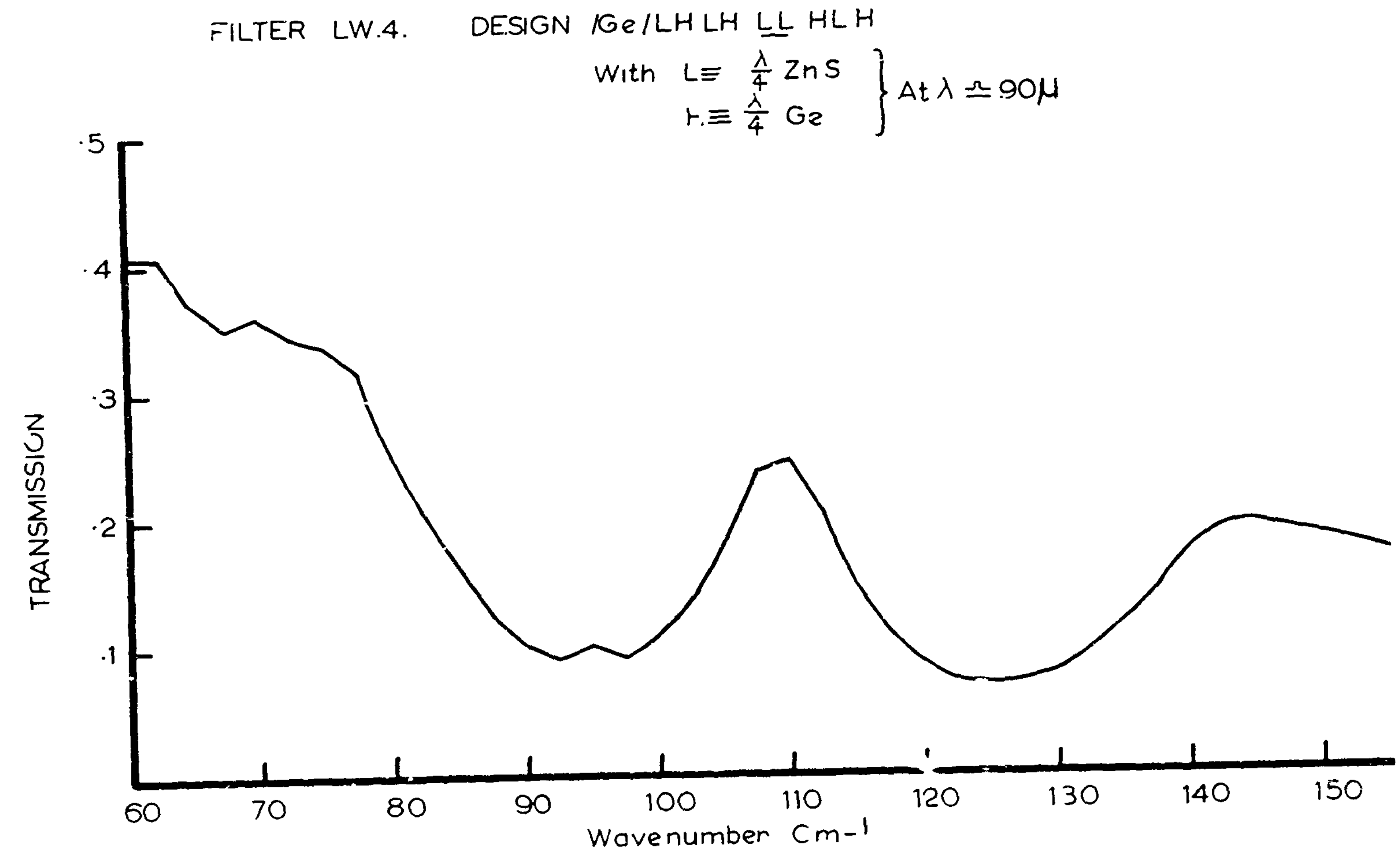


FIG 4.15. TRANSMISSION OF FILTER L.W.4 ON Ge SUBSTRATE AS MEASURED BY IRIS INTERFEROMETER.

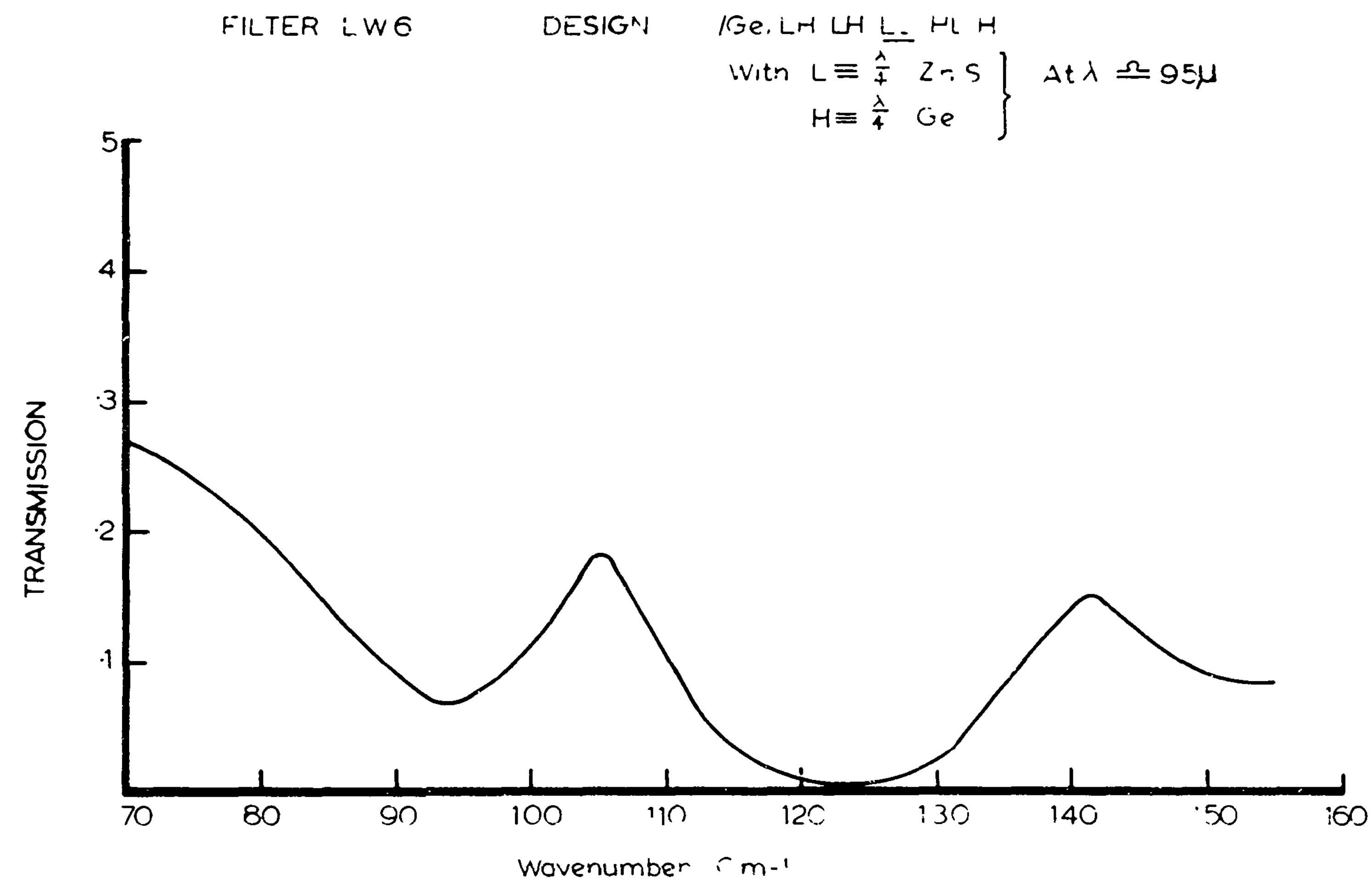


FIG. 4·16 TRANSMISSION OF LW6 ON Ge SUBSTRATE AS MEASURED BY THE GM3 SPECTROMETER.

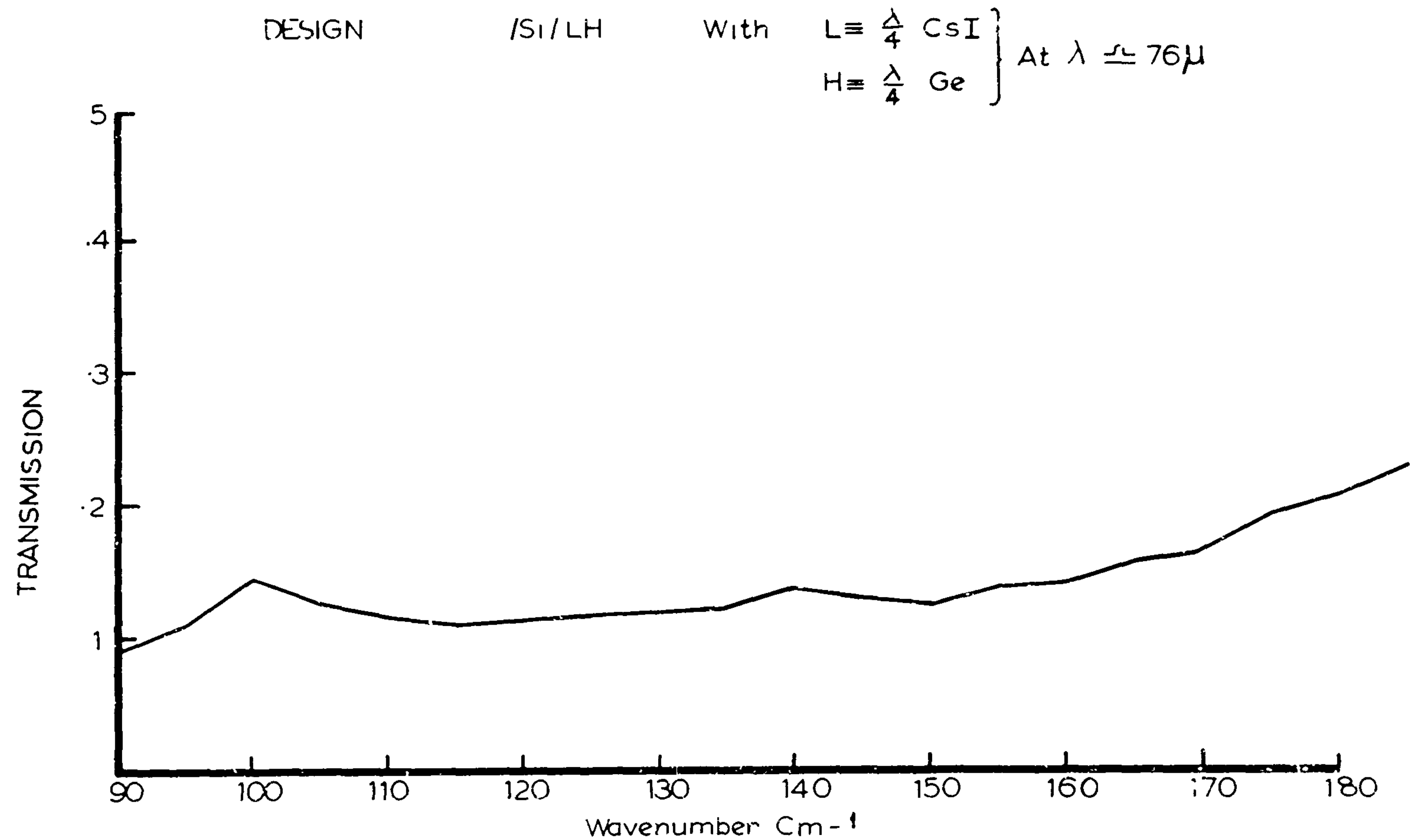


FIG 4.17. TRANSMISSION OF /Si/LH AS MEASURED BY THE IRIS INTERFEROMETER

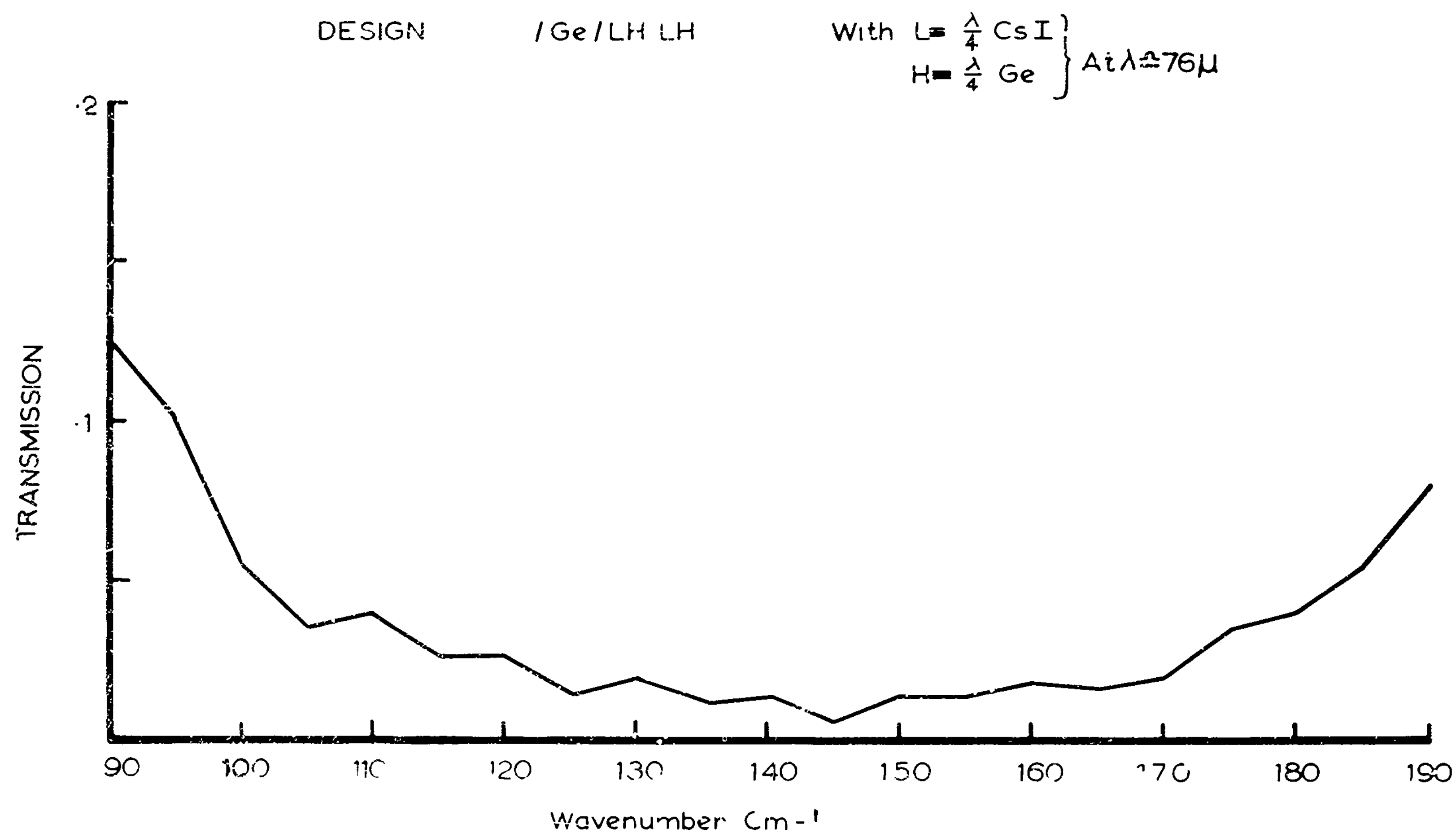


FIG 4.18. TRANSMISSION OF /Ge/LHLH AS MEASURED BY THE IRIS INTERFEROMETER.

FILTER DESIGN

$$\left.\begin{array}{l} L/SL/LH\underline{LL}H \\ \text{With } L = \frac{\lambda}{4}\ CsI \\ \qquad H = \frac{\lambda}{4}\ Ge \end{array}\right\} \text{At } \lambda = 75\mu$$

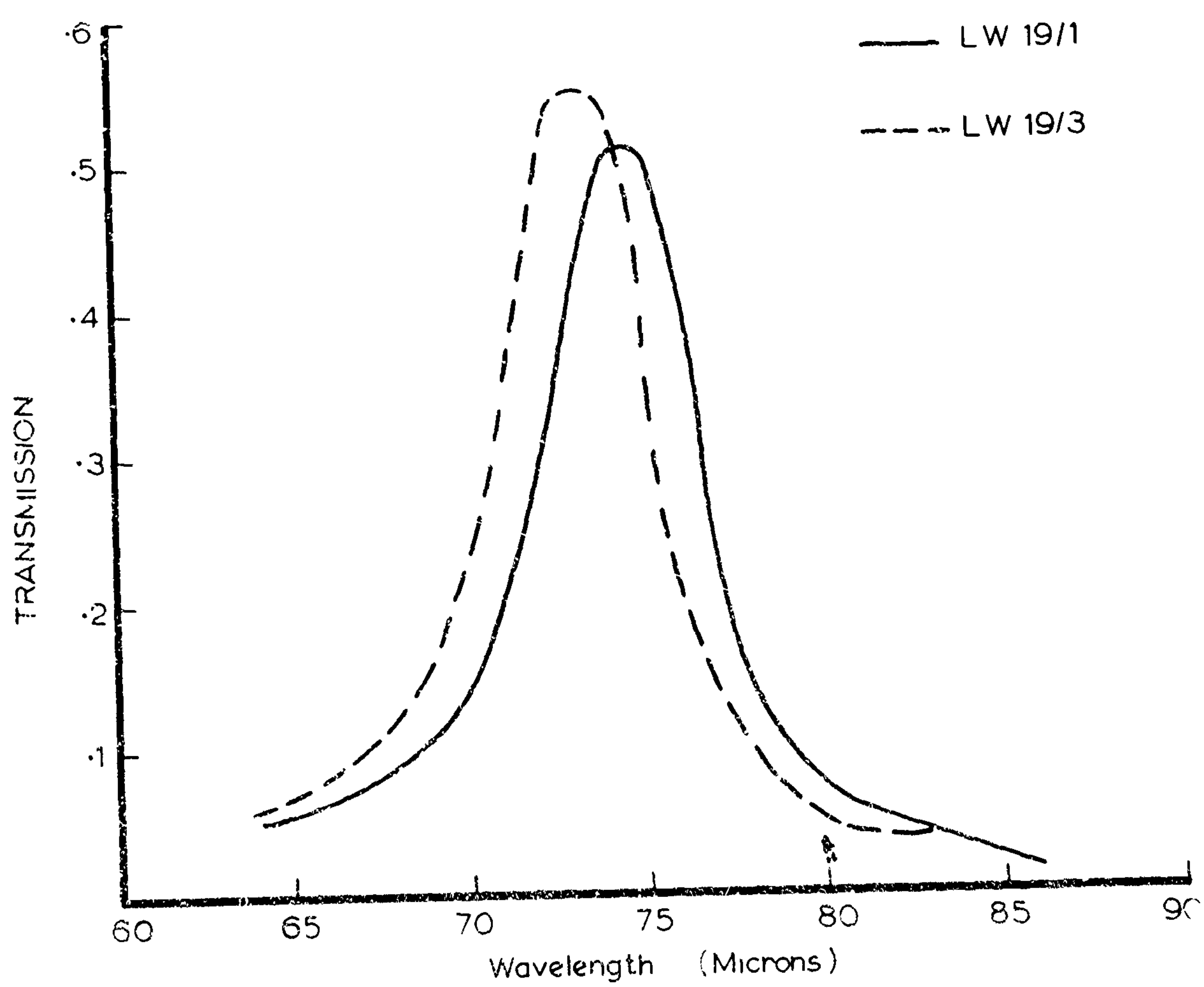


FIG. 4.19. MEASURED TRANSMISSION OF NARROW BAND PASS FILTERS LW19/1 & LW19/3.

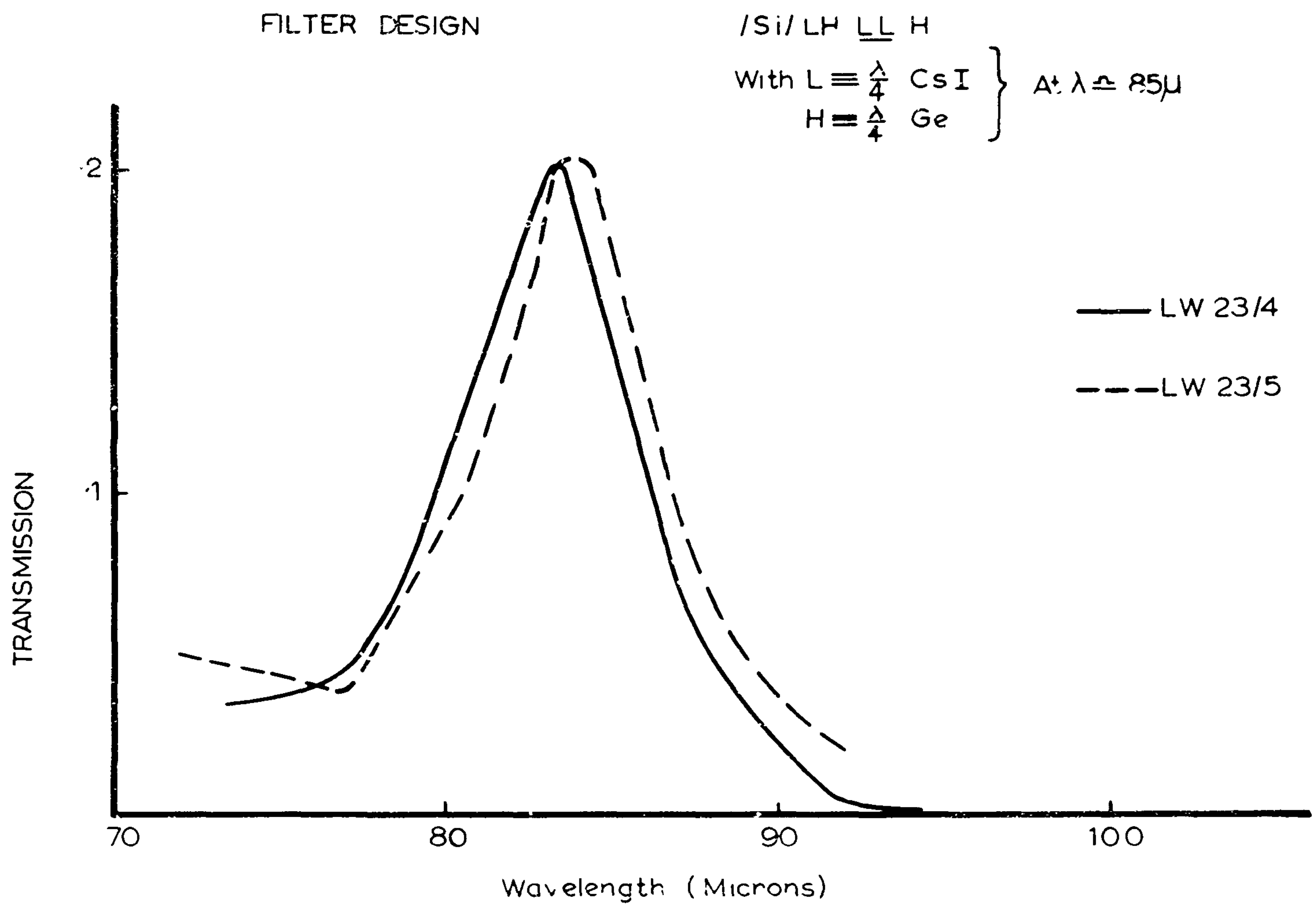


FIG. 4.20. MEASURED TRANSMISSION OF NARROW BAND PASS FILTERS LW23/4 & LW23/5

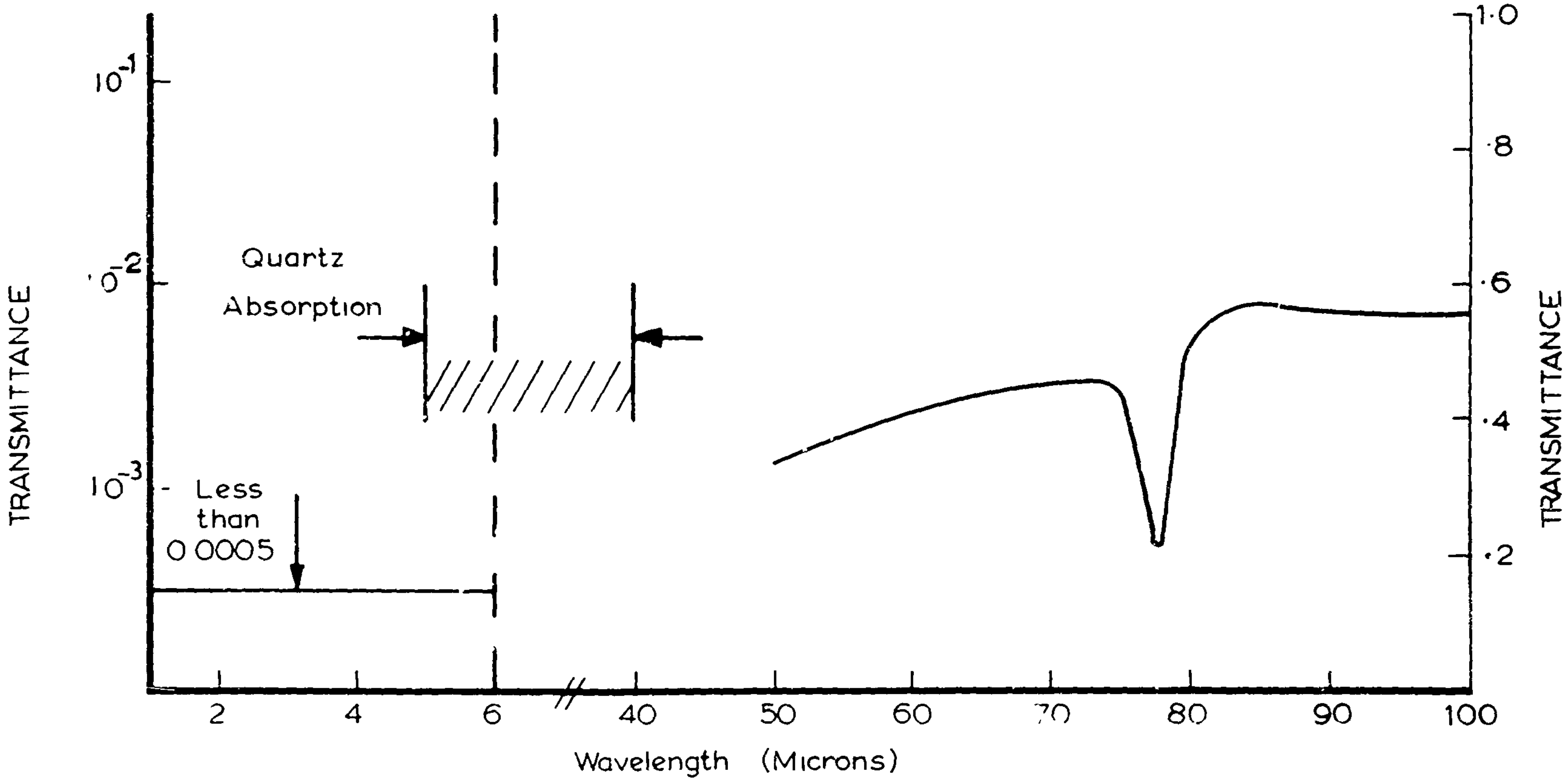


FIG. 4.21. TRANSMISSION OF QUARTZ LOW PASS FILTER AQ/2.

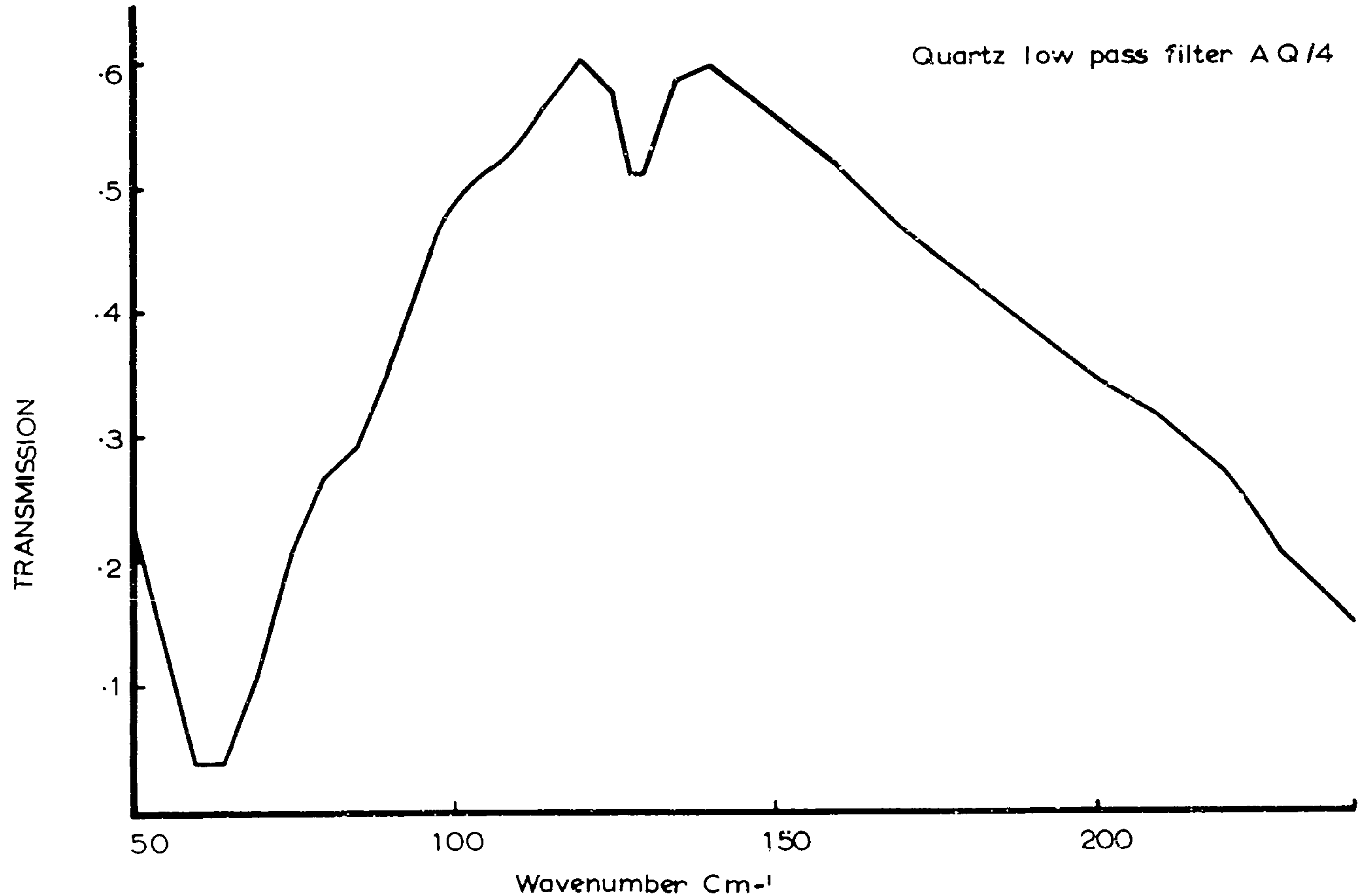


FIG.4.22. FAR INFRARED TRANSMISSION OF QUARTZ LOW PASS FILTER AQ/4 AS MEASURED BY CUBE INTERFEROMETER. AT 5 Cm $^{-1}$ RESOLUTION.

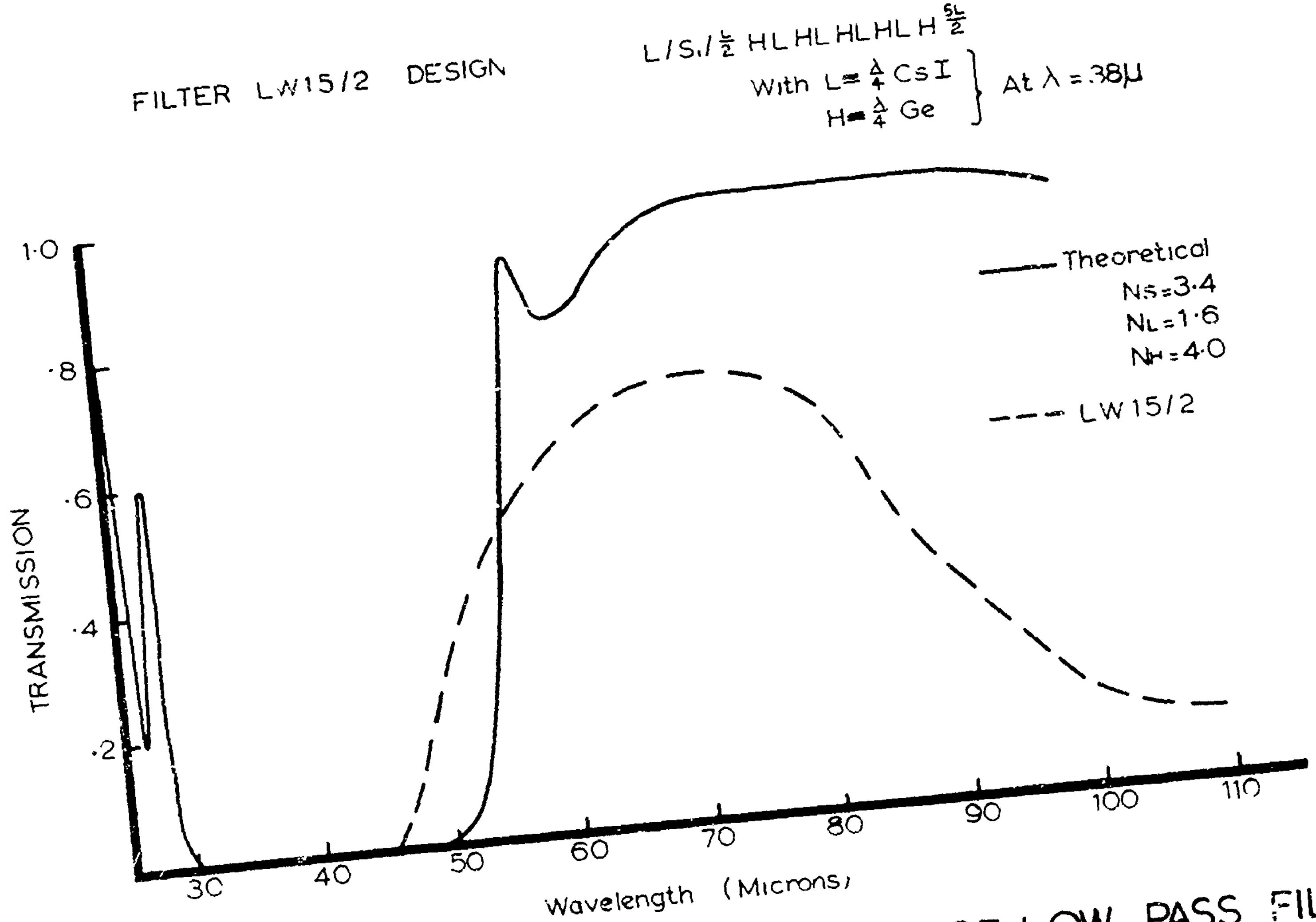


FIG 4.23. MEASURED TRANSMISSION OF LOW PASS FILTER LW15/2 COMPARED WITH THEORETICAL DESIGN ON A SEMI-INFINITE SUBSTRATE.

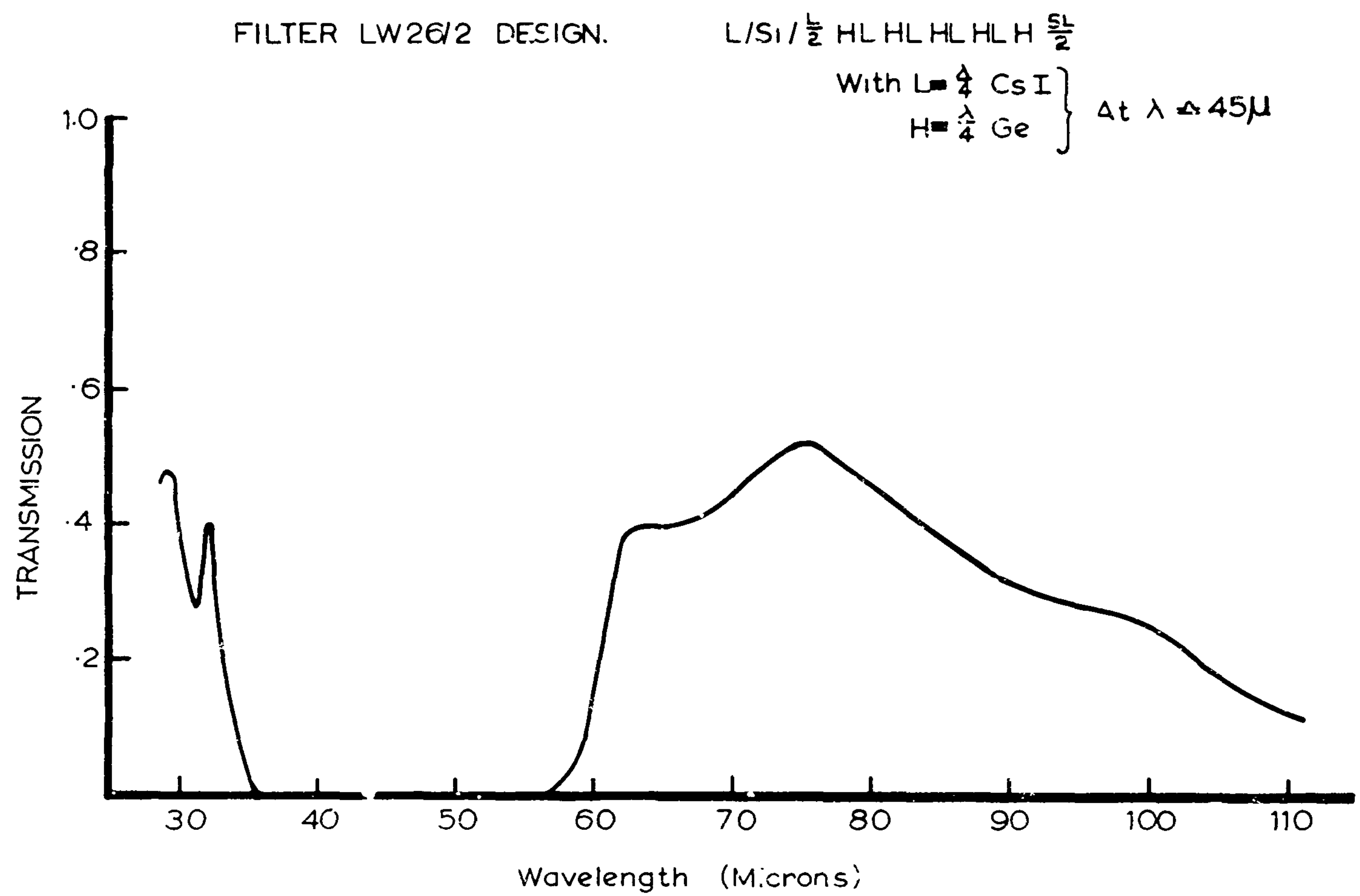


FIG. 4.24. MEASURED TRANSMISSION OF LOW PASS FILTER LW26/2 SHOWING EXTENT OF STOP REGION.

FILTER DESIGN $\quad \frac{H'}{2}\, L'\, \frac{H'}{2} / Si / \frac{'}{2}\, HL\, HL\, HL\, HL\, H\, \frac{L}{2}\, \frac{H'}{2}\, L'\, \frac{H'}{2}$

$$\left.\begin{array}{ll} \text{With } L \equiv \frac{\lambda}{4} & CsI \\ H \equiv \frac{\lambda}{4} & Ge \end{array}\right\} \text{AT } \lambda = 45\mu$$

$$\left.\begin{array}{ll} L' \equiv \frac{\lambda}{4} & CsI \\ H' \equiv \frac{\lambda}{4} & Ge \end{array}\right\} \text{AT } \lambda = 38\mu$$

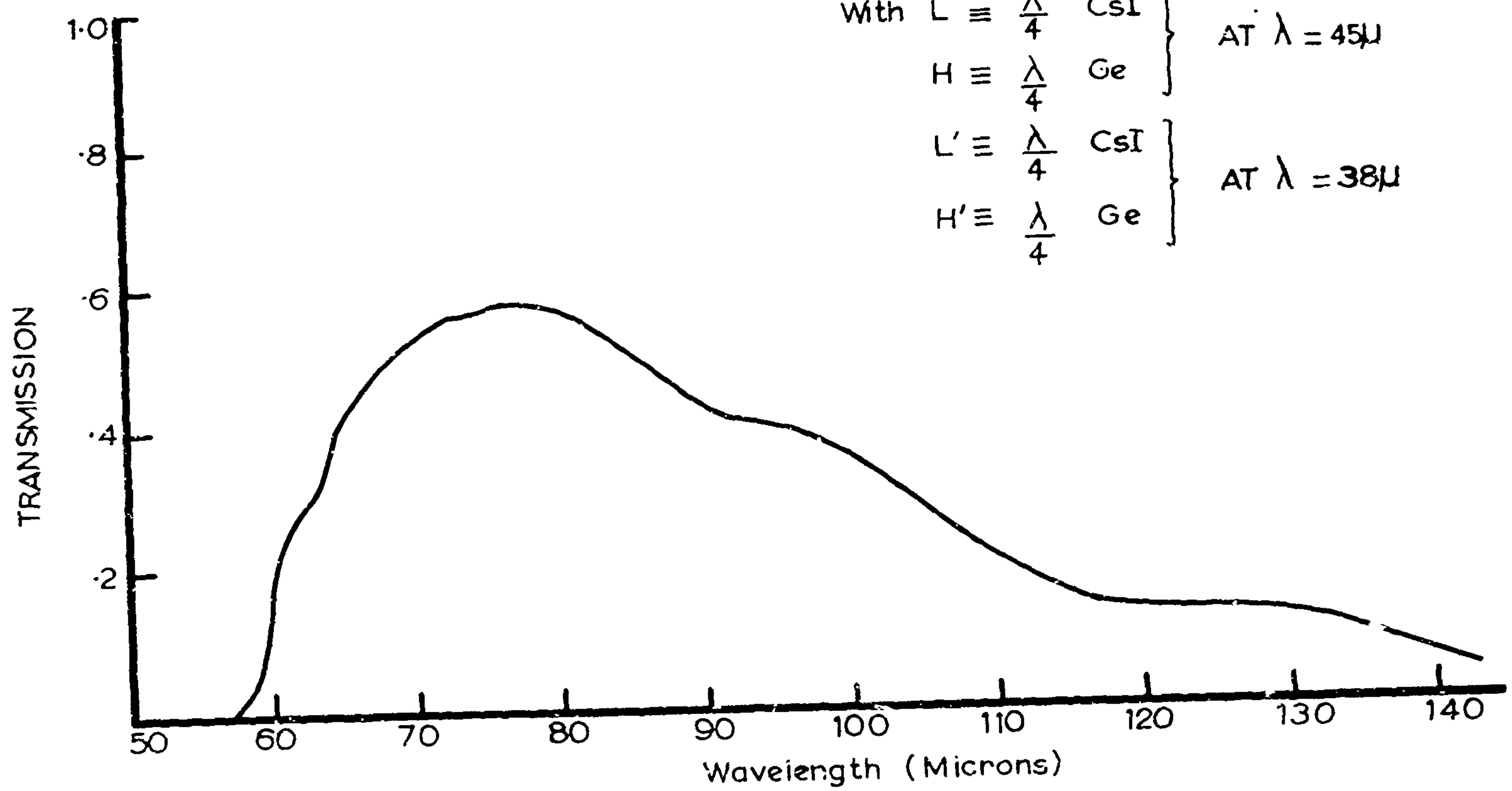
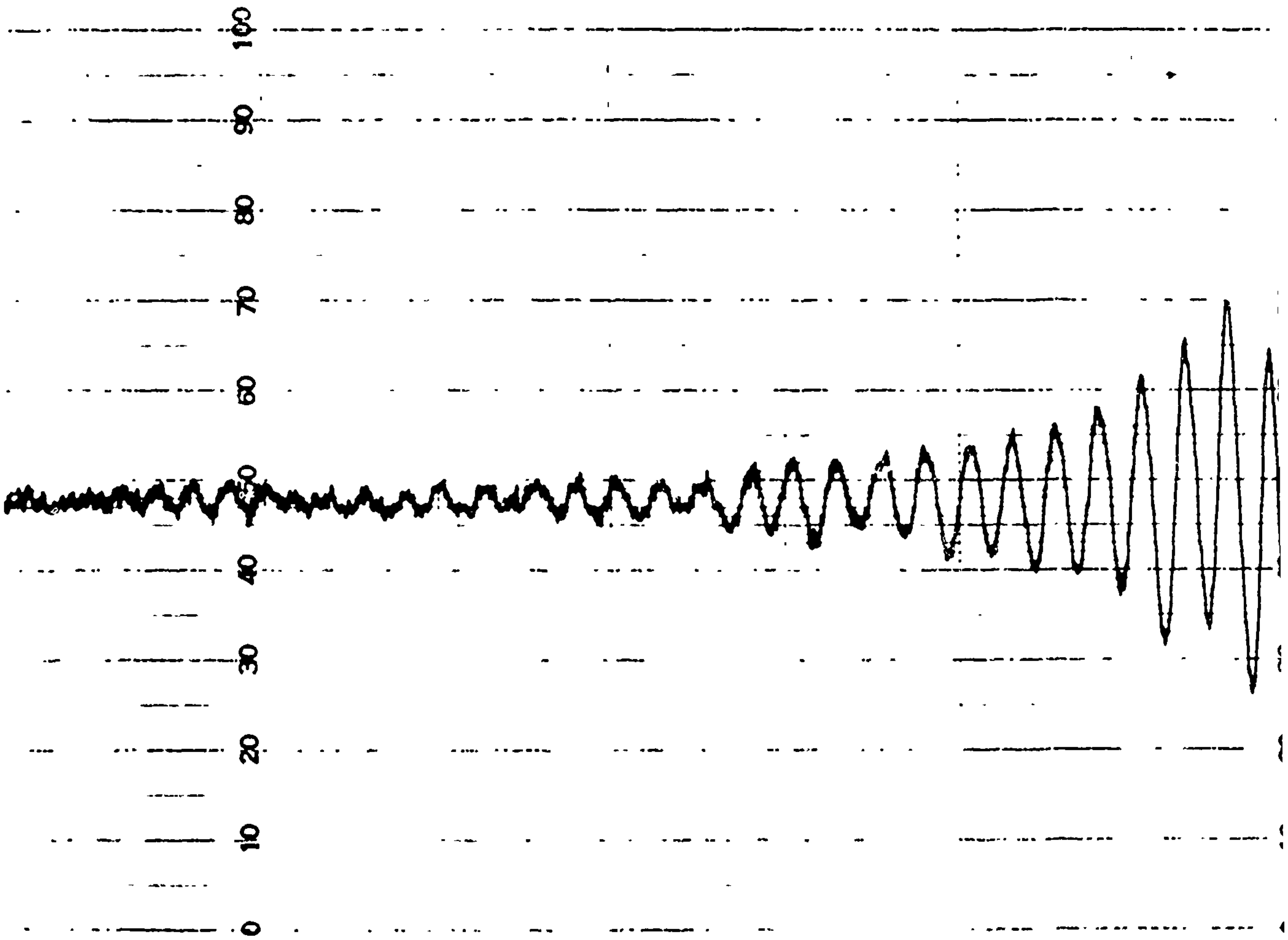


FIG. 4.25. TRANSMISSION OF LOW PASS FILTER LW28/1 AS MEASURED BY THE CUBE INTERFEROMETER



·D. CALIFORNIA CHART NO. 5R

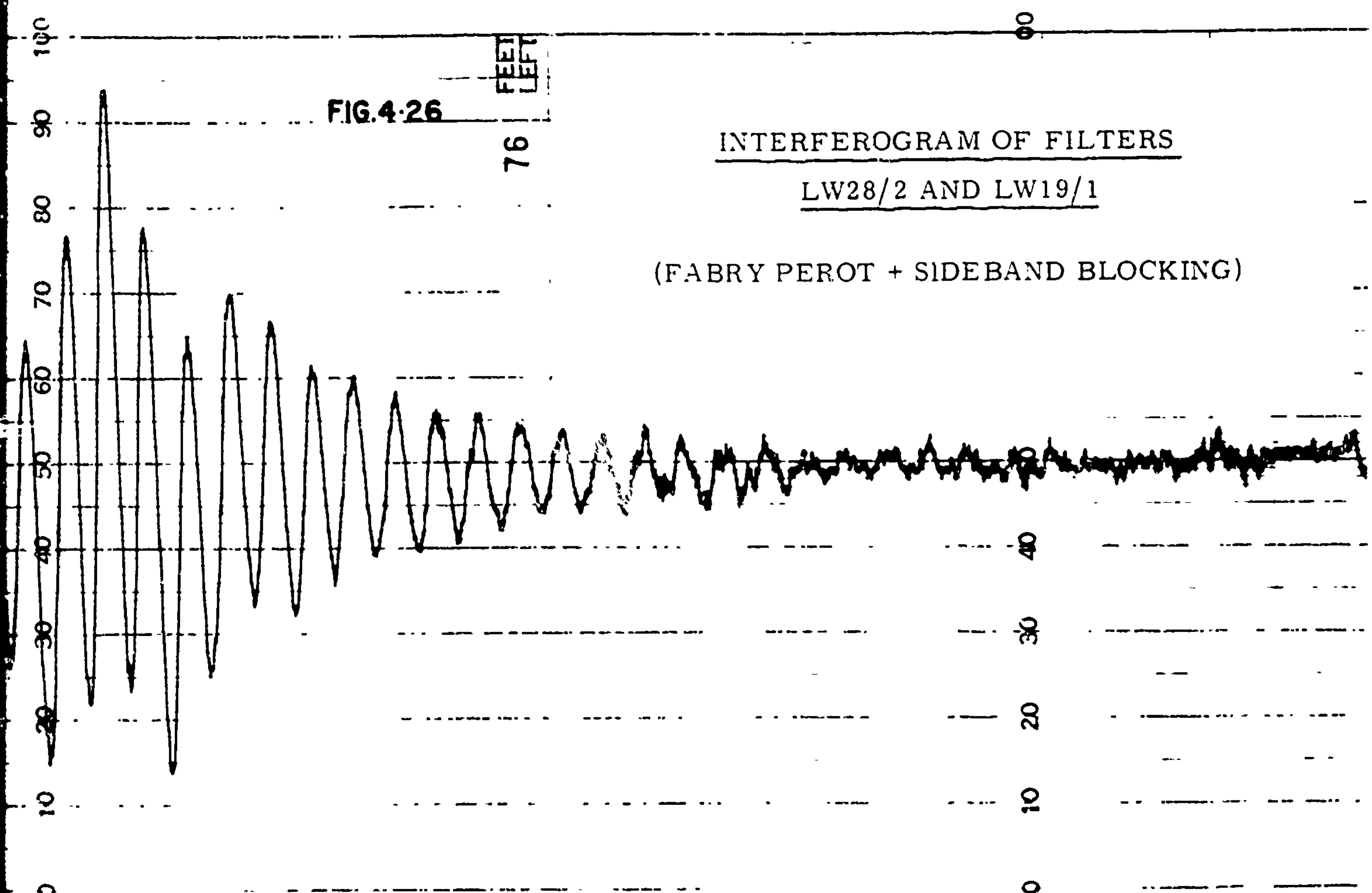
A

FIG.4·26

76 FEET LEFT

INTERFEROGRAM OF FILTERS
LW28/2 AND LW19/1

(FABRY PEROT + SIDEBAND BLOCKING)



HESCO INSTRUMENTS, DIVISION OF DATAPULSE INCORPORATED INGLEWOOD CALIFORNIA

CHART NO 5R

15

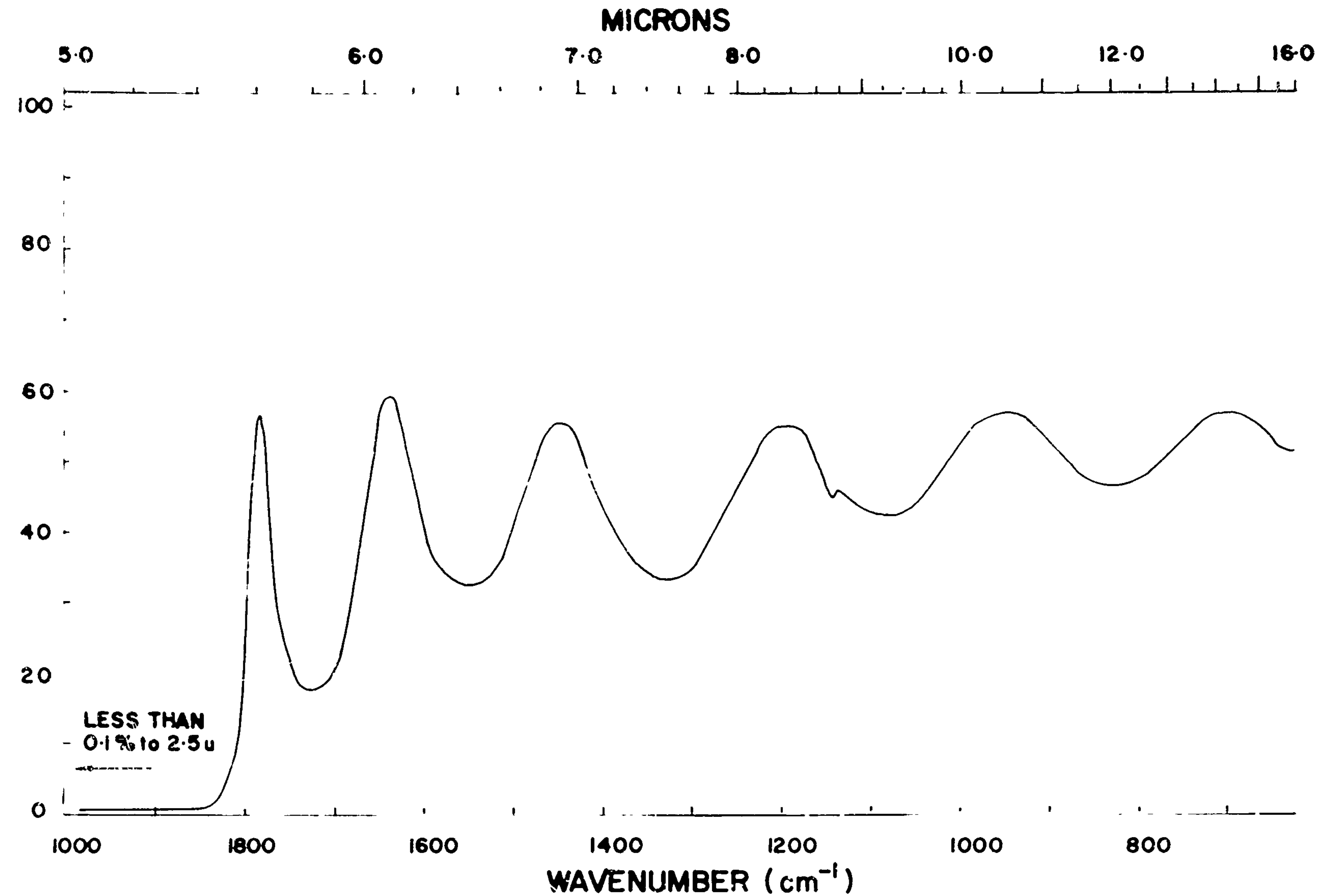


FIG. 4·28 SHORTWAVE TRANSMISSION of 16 LAYER PbTe/ZnS BLOCKING STACK (on Ge)

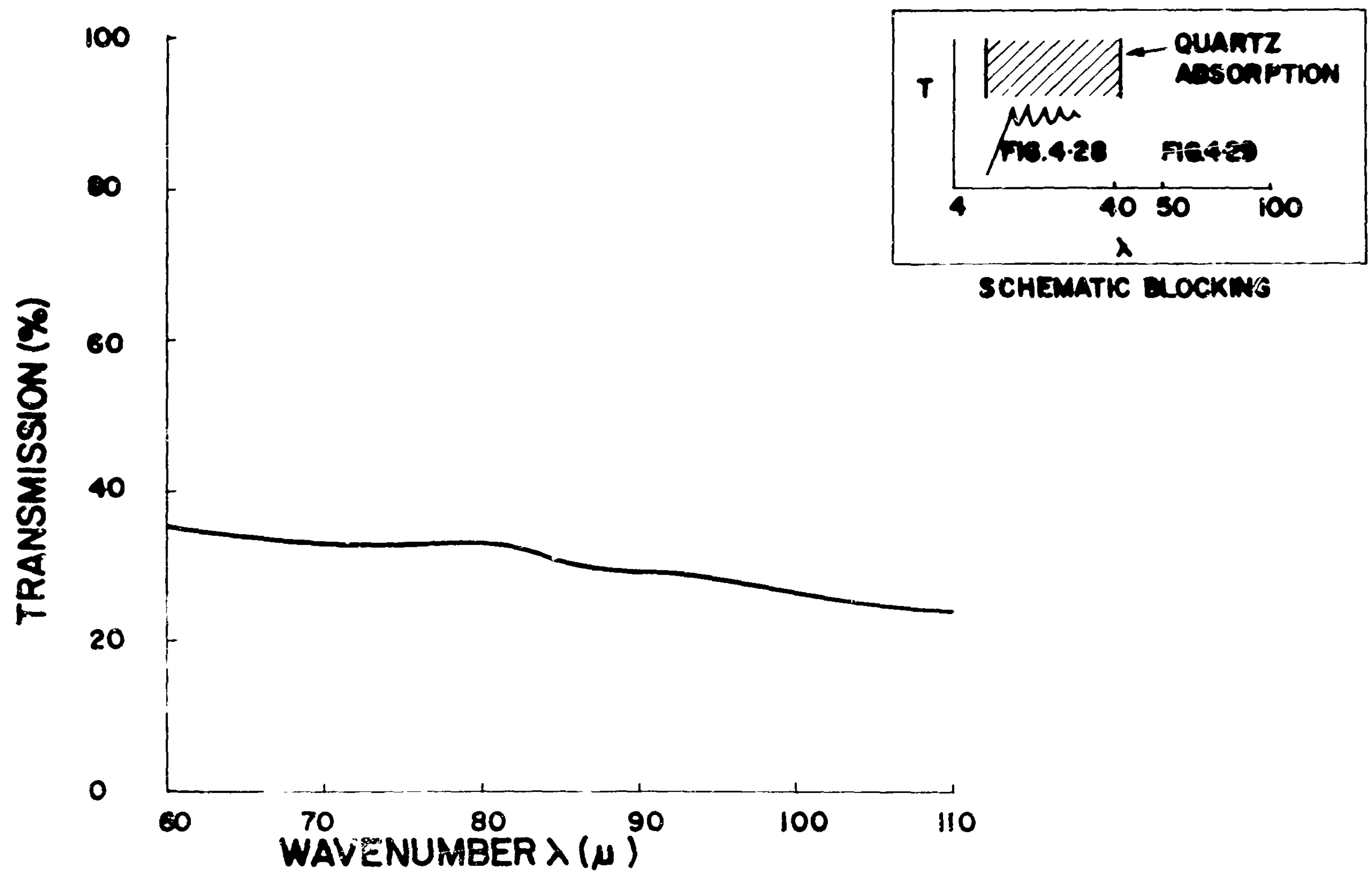


FIG. 4·29 LONGWAVE TRANSMITTANCE of PbTe/ZnS STACK

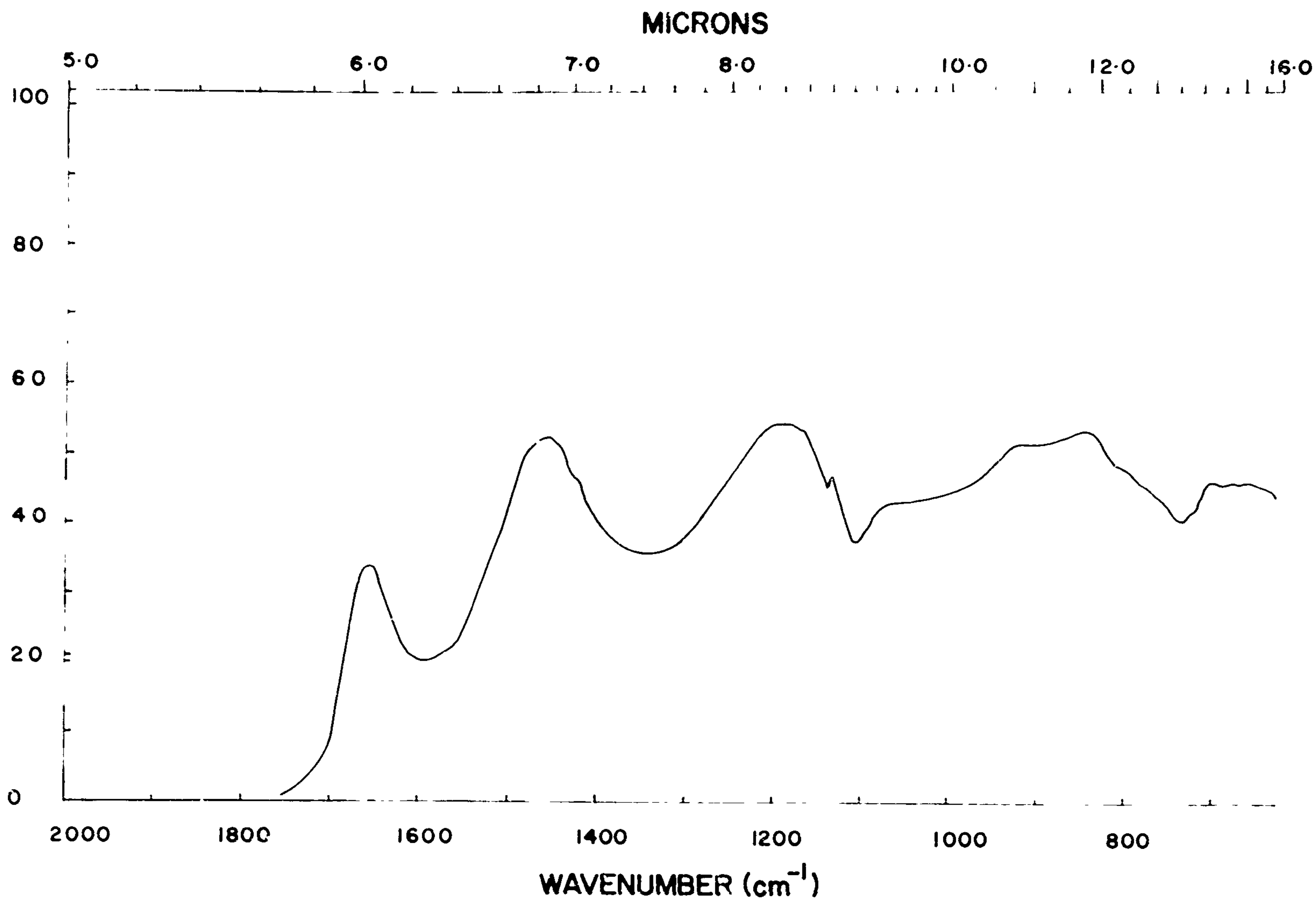


FIG. 4·30 SHORTWAVE TRANSMISSION of 12 LAYER PbTe/CsI STACK (on Si)

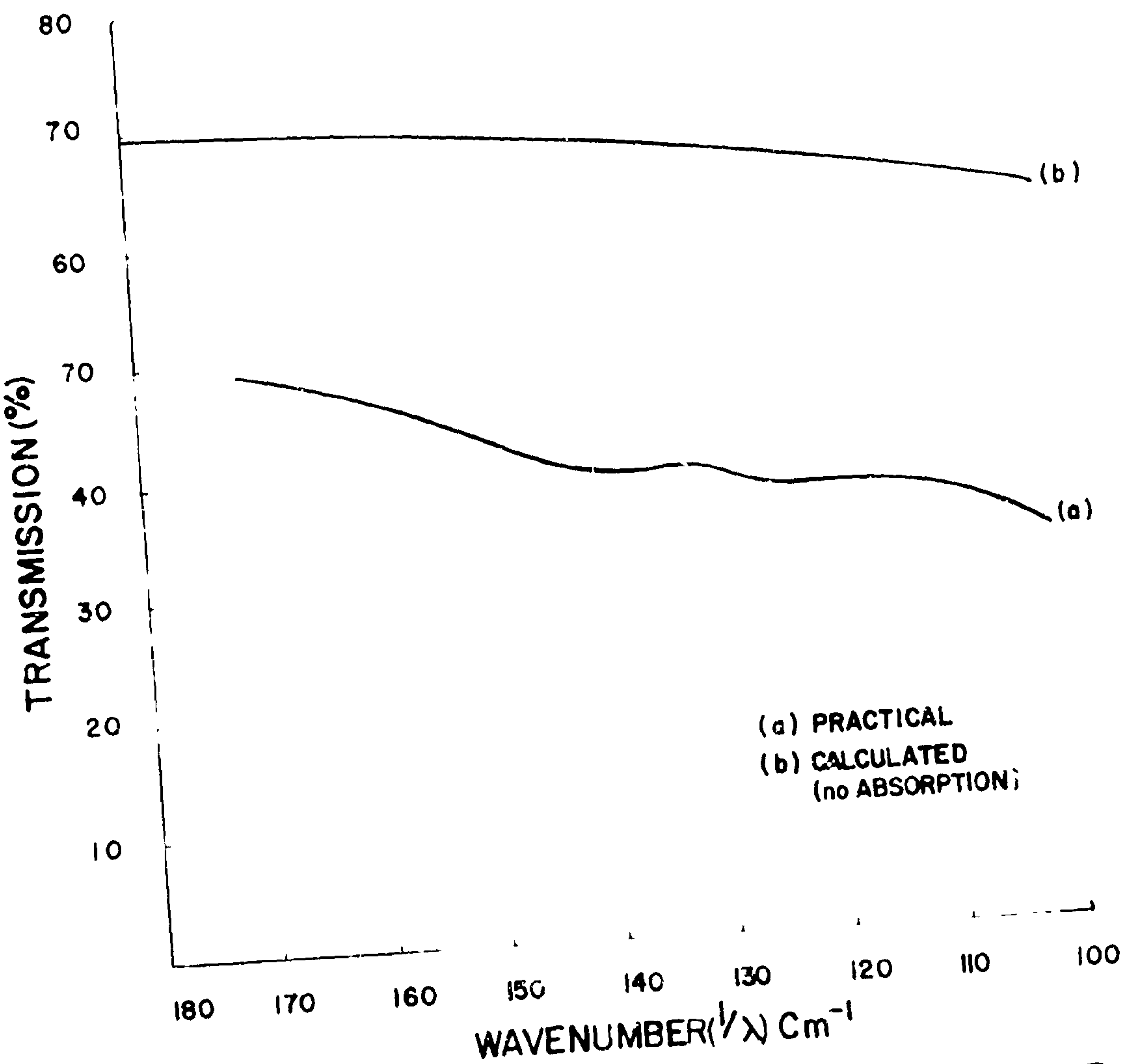


FIG. 4·31 LONGWAVE TRANSMISSION of Pb Te/CsI
STACK NO. 048/1

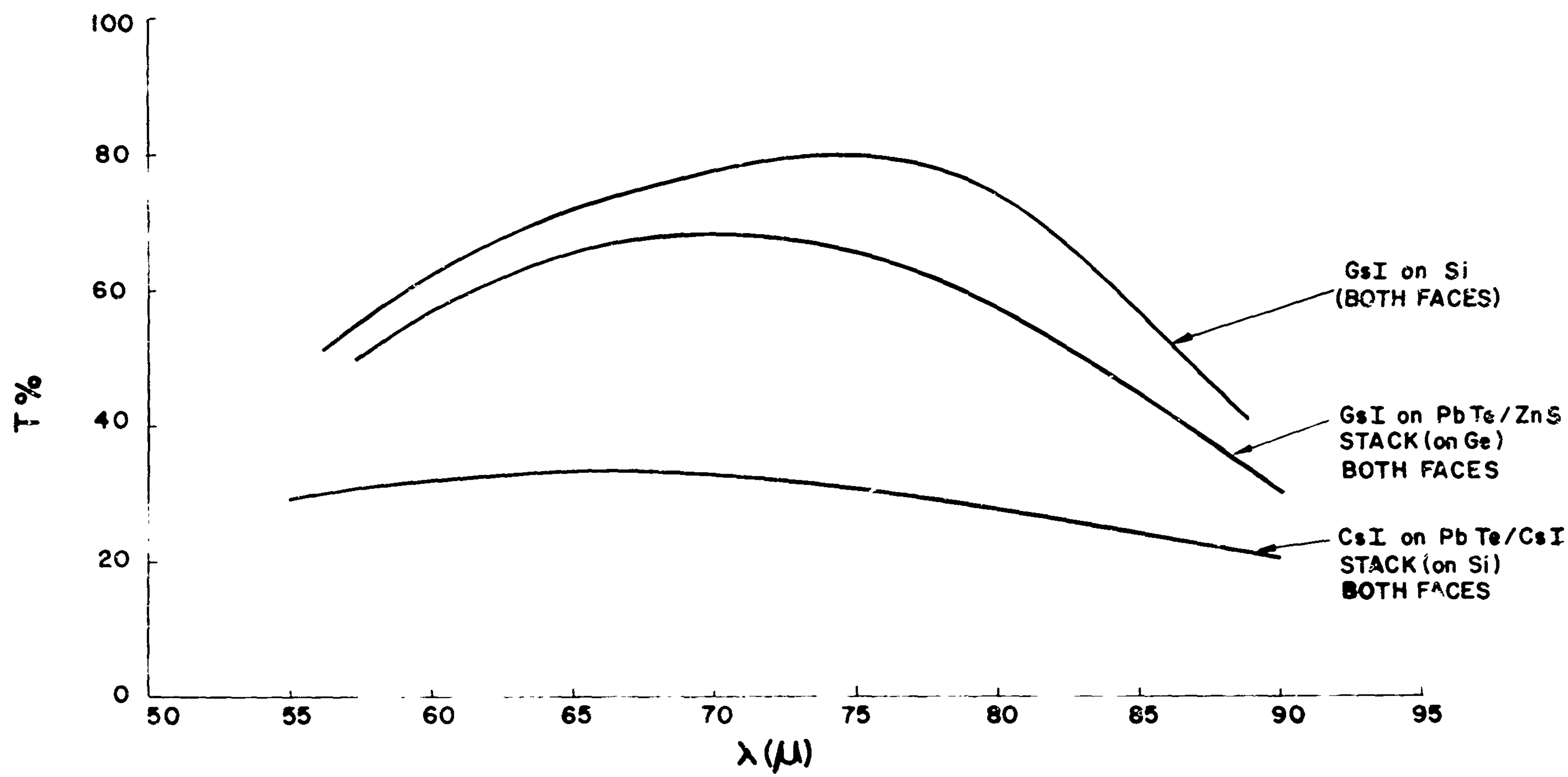


FIG. 4·32 CsI ANTIREFLECTION at 75μ
(27 QWOT at 3·93 μ)

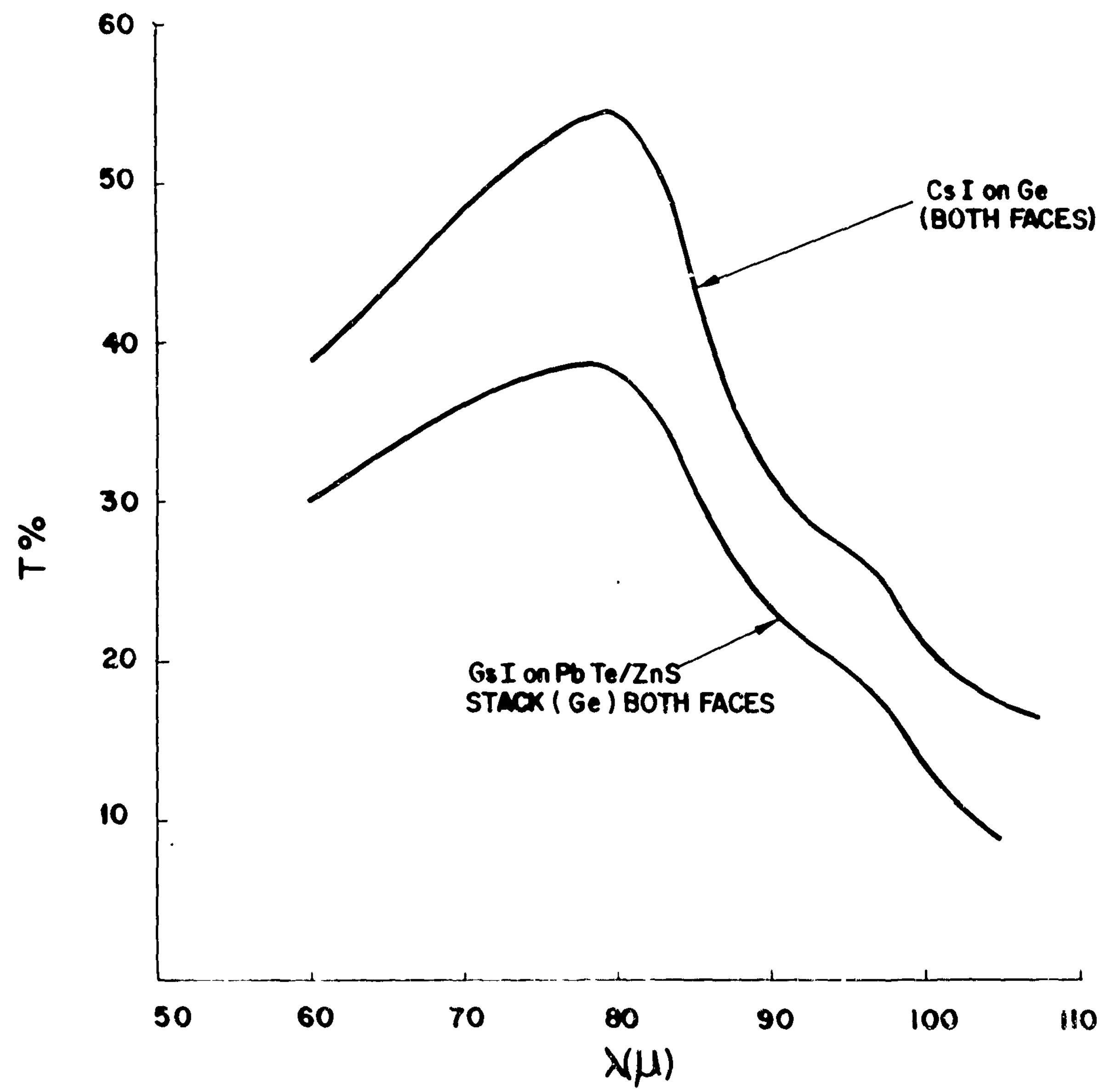


FIG. 4·33 Cs I ANTIREFLECTION at 85μ
(33 QWOT at 3·93μ)

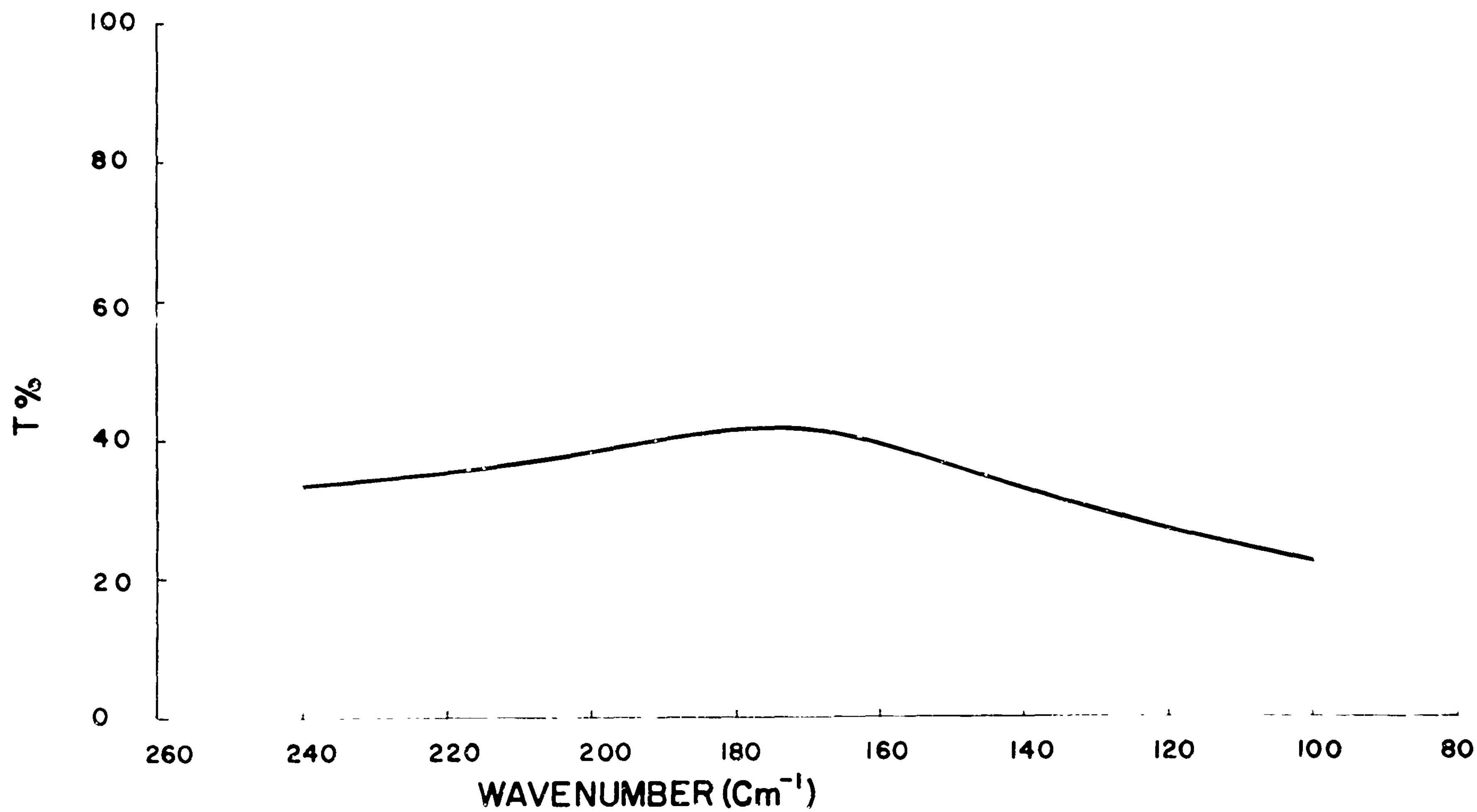


FIG 4·34 LONGWAVE TRANSMITTANCE of 16 LAYER
PbTe/CsBr STACK (WITHOUT ANTIREFLECTION)

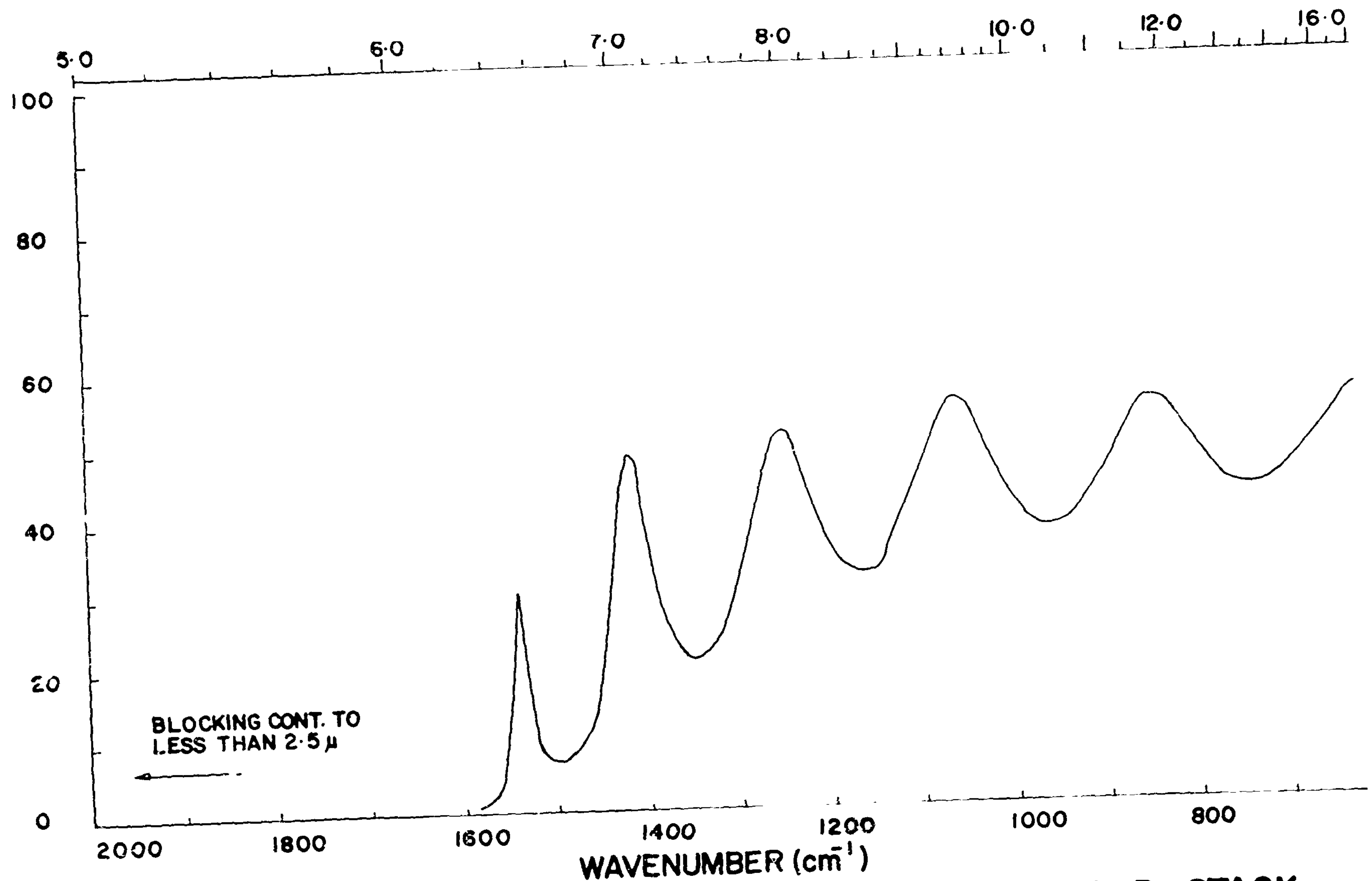


FIG. 4·35 SHORTWAVE TRANSMISSION of Pb Te/CsBr STACK

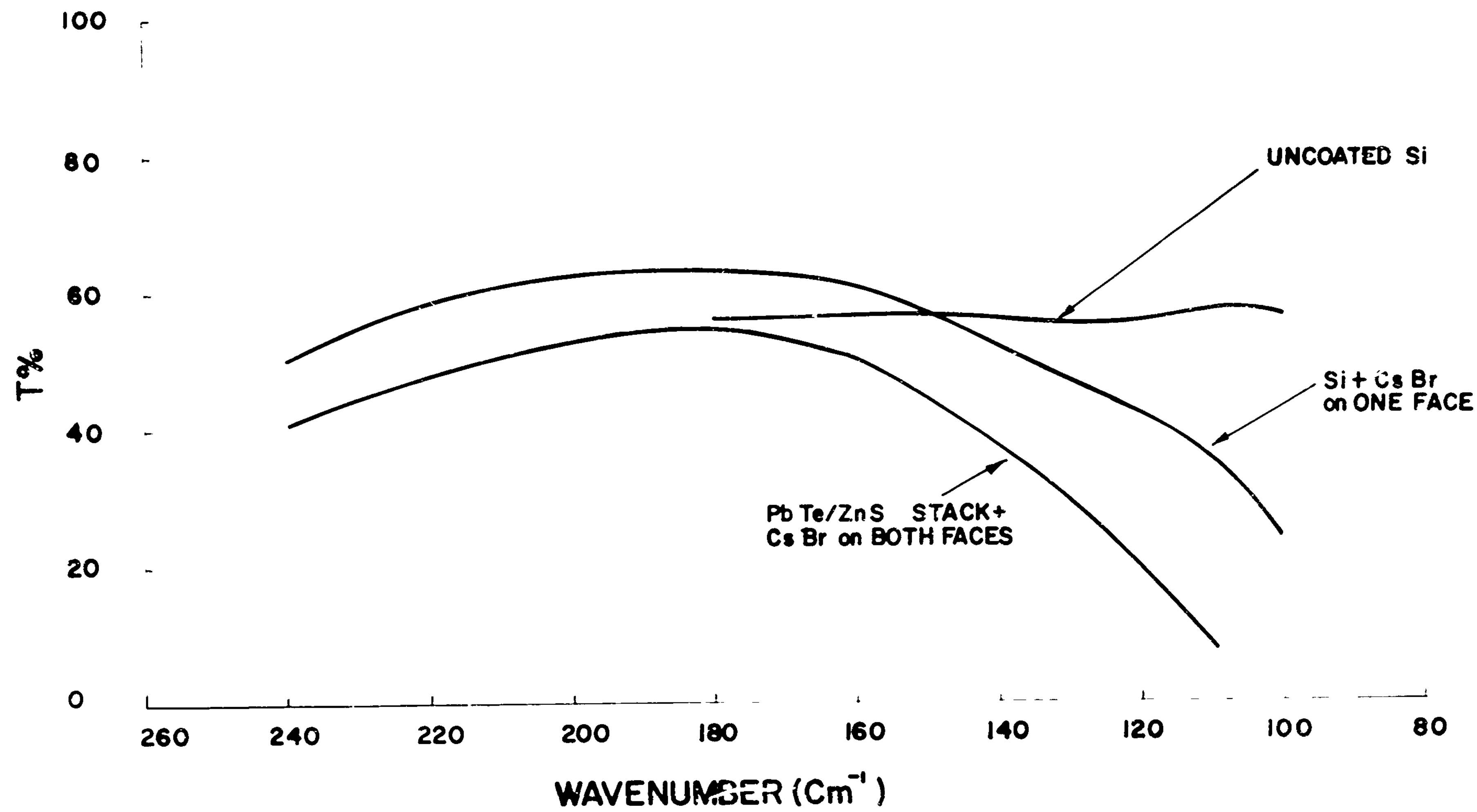


FIG. 4·36 CsBr ANTIREFLECTION (19 QWOT at 3·93 μ)

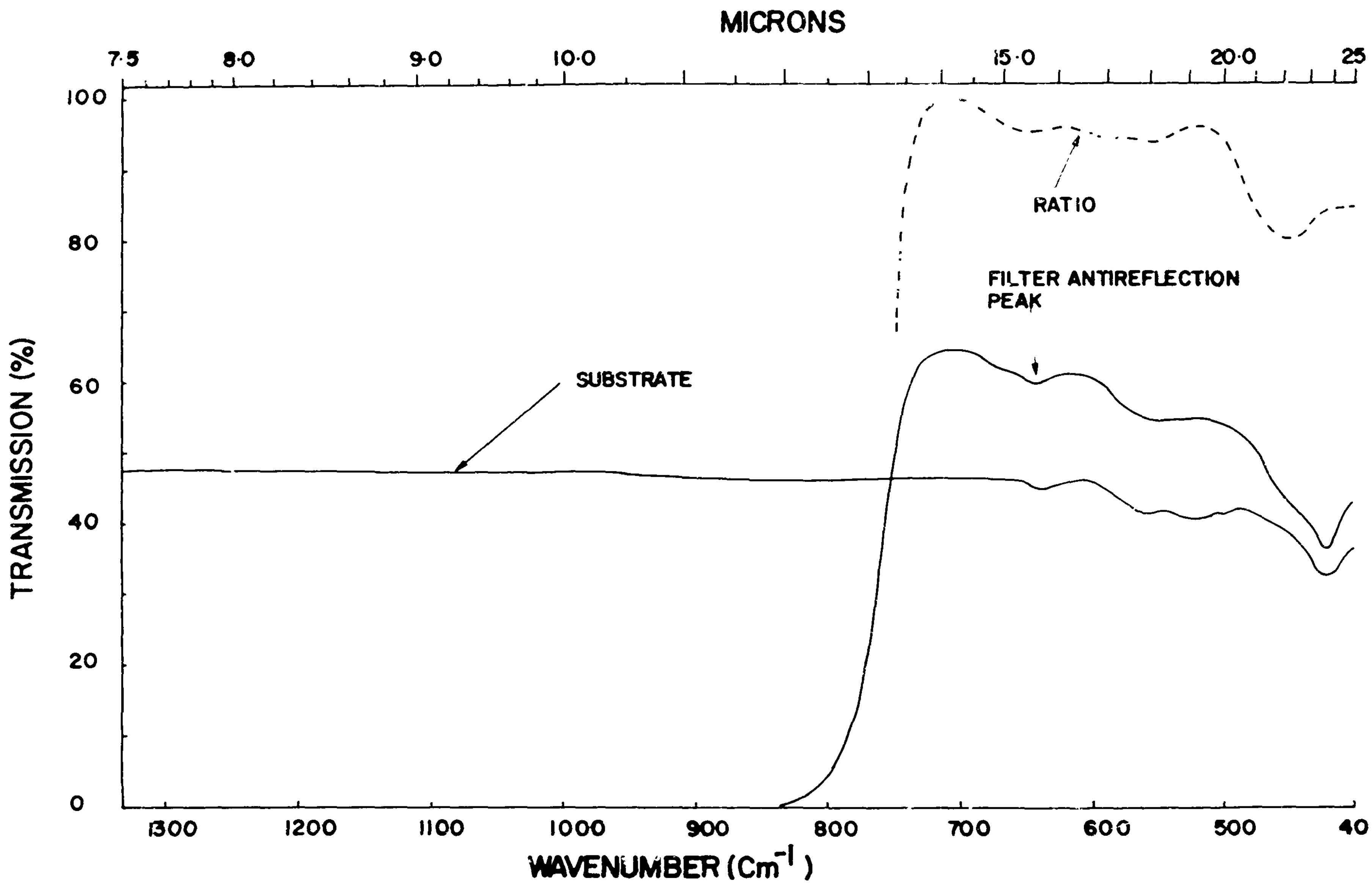


FIG. 4·37 EQUAL—RIPPLE PbTe / ZnS LOWPASS FILTER

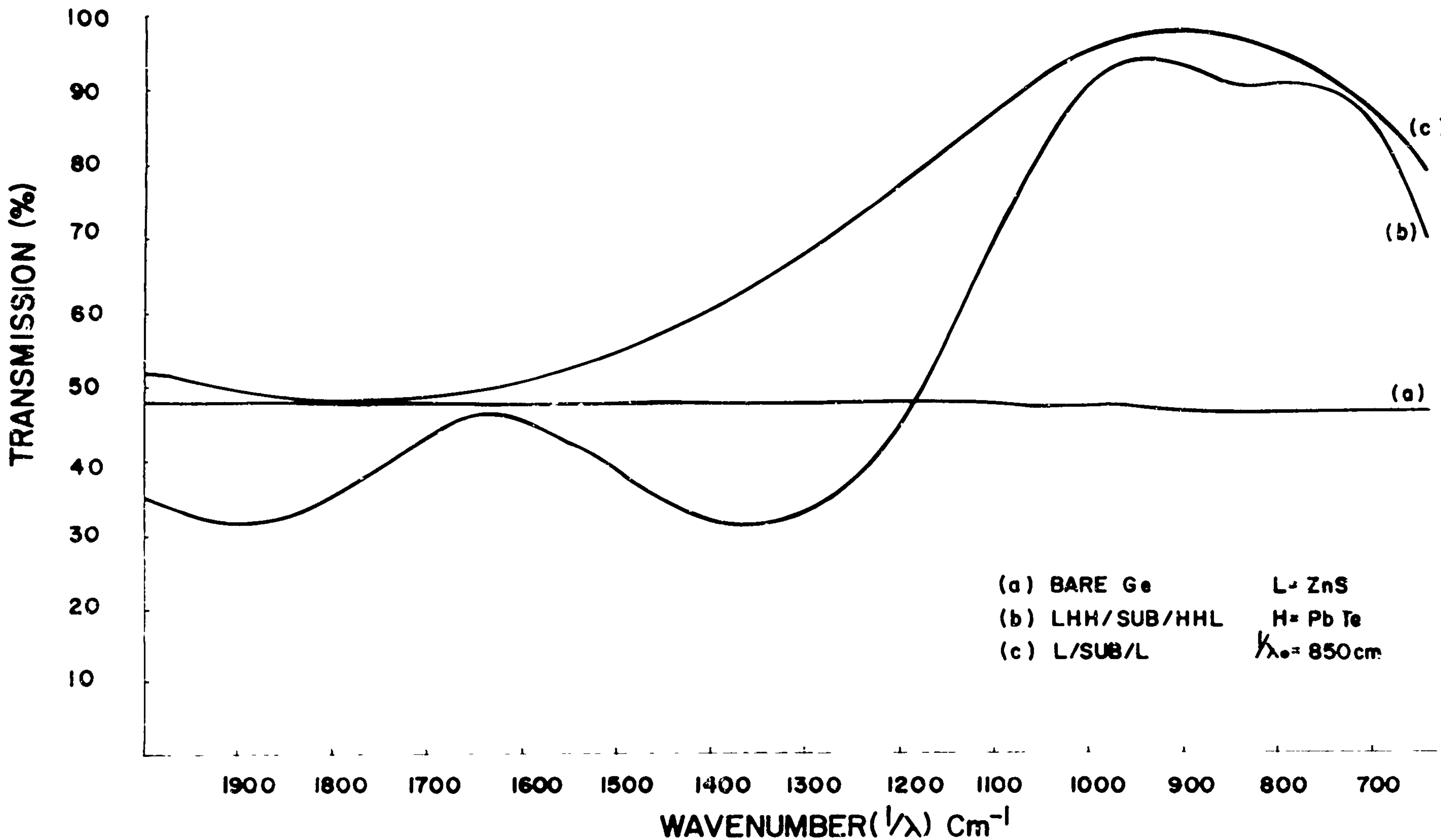


FIG. 4·38 ANTIREFLECTION of GERMANIUM

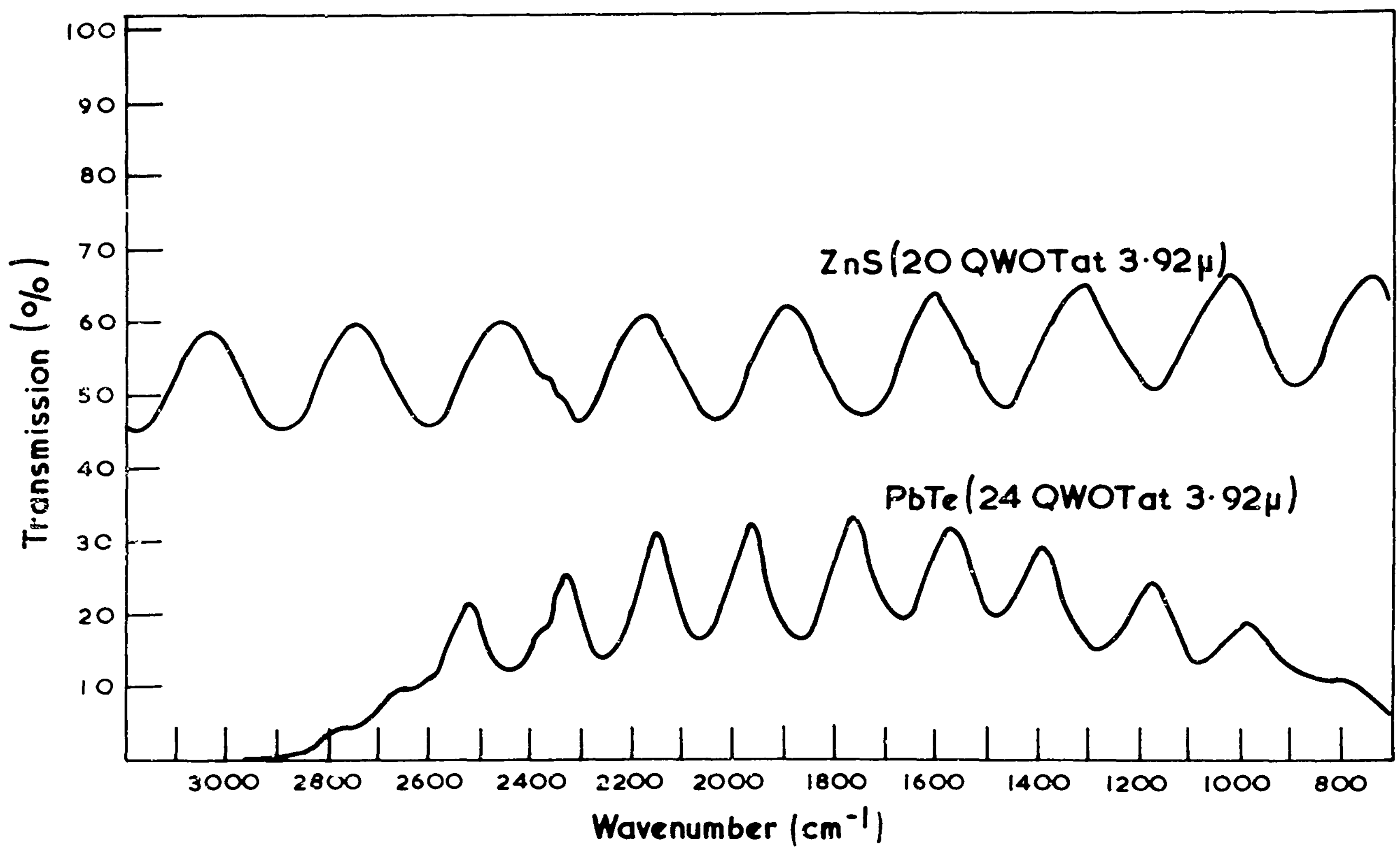


Fig: 4.39 TRANSMISSION OF PbTe AND ZnS COLLECTED SEPARATELY DURING A FILTER DEPOSITION

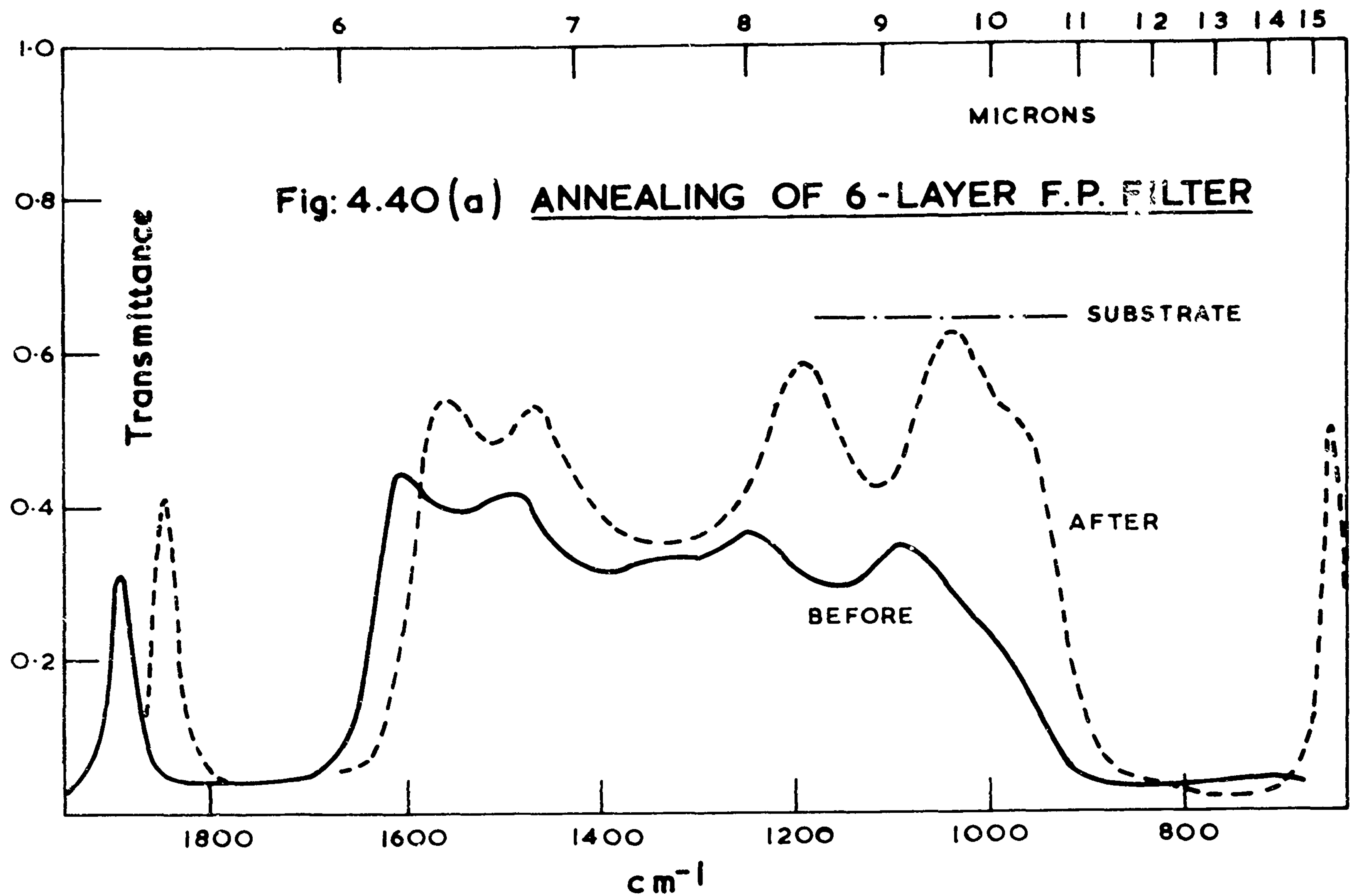


Fig: 4.40 (a) ANNEALING OF 6-LAYER F.P. FILTER
MICRONS
6
7
8
9
10
11
12
13
14
15
Transmittance
1·0
0·8
0·6
0·4
0·2
SUBSTRATE
AFTER
BEFORE
1800
1600
1400
1200
1000
800
cm⁻¹

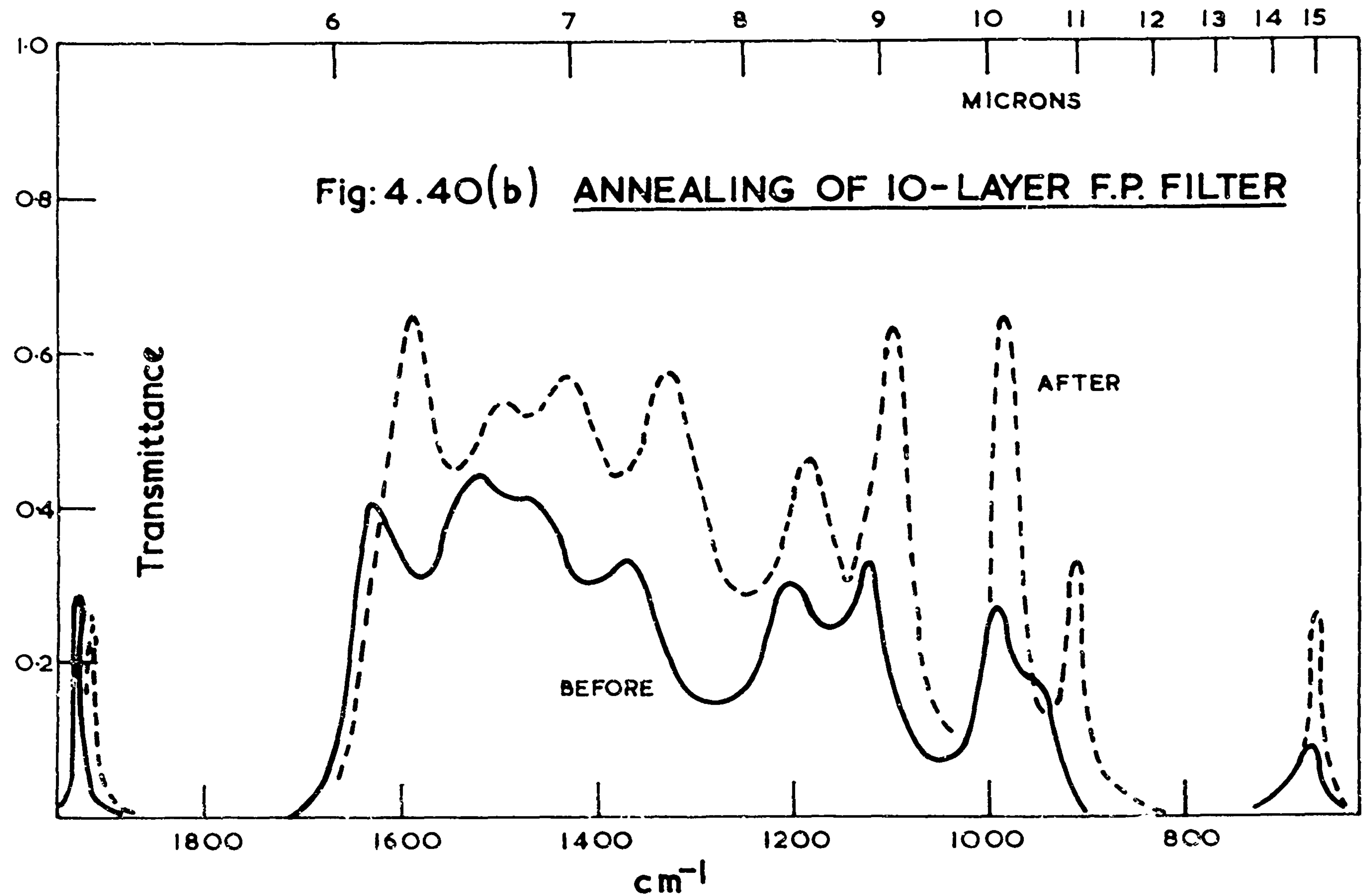


Fig: 4.40(b) ANNEALING OF 10-LAYER F.P. FILTER

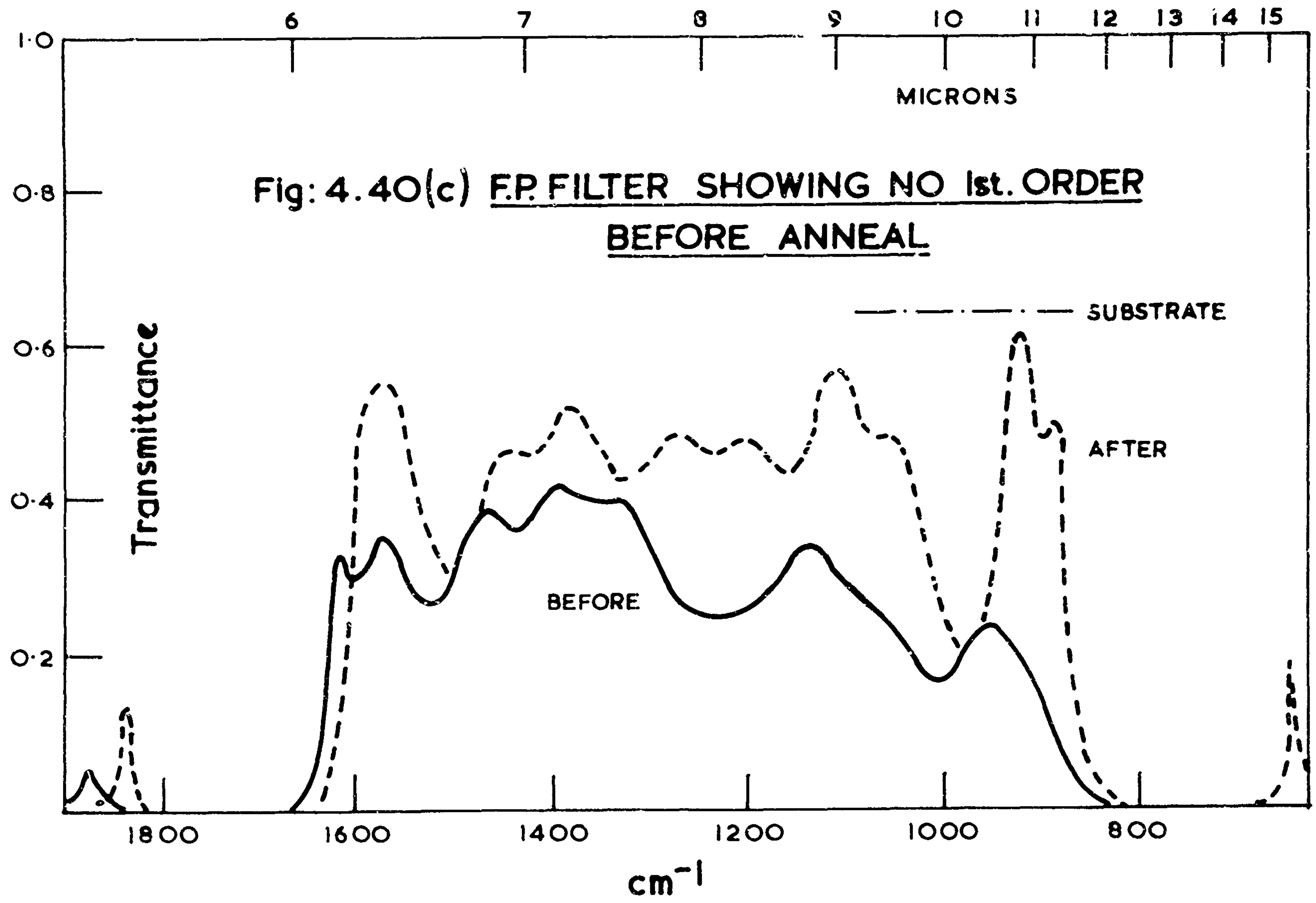


Fig: 4.40(c) F.P. FILTER SHOWING NO Ist. ORDER BEFORE ANNEAL
MICRONS
6
7
8
9
10
11
12
13
14
15
1·0
0·8
0·6
0·4
0·2
Transmittance
SUBSTRATE
AFTER
BEFORE
1800
1600
1400
1200
1000
800
cm^{-1}

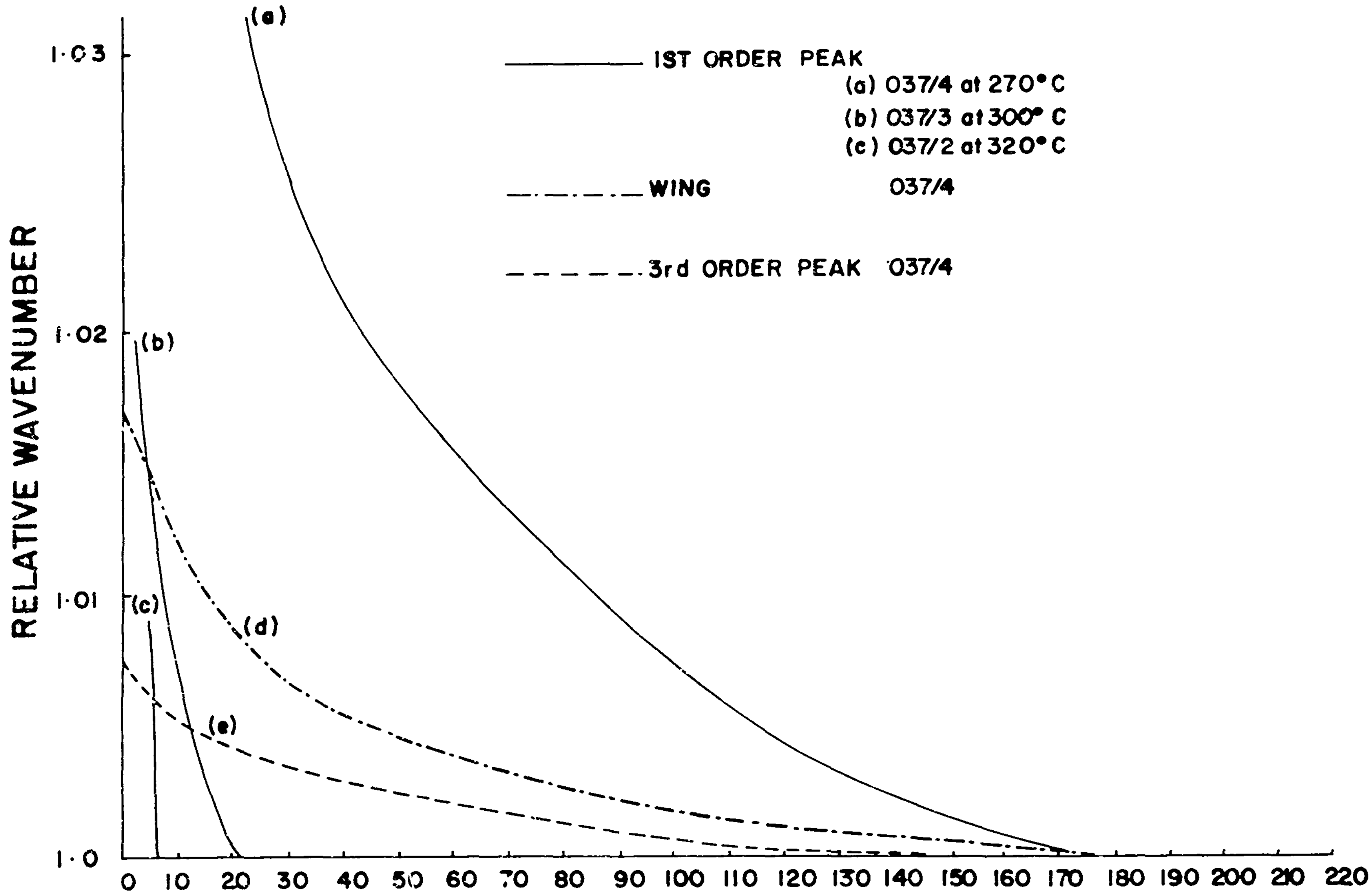


FIG. 4·41 (a) SPECTRAL SHIFT of F.P. PEAKS at VARIOUS TEMPERATURES

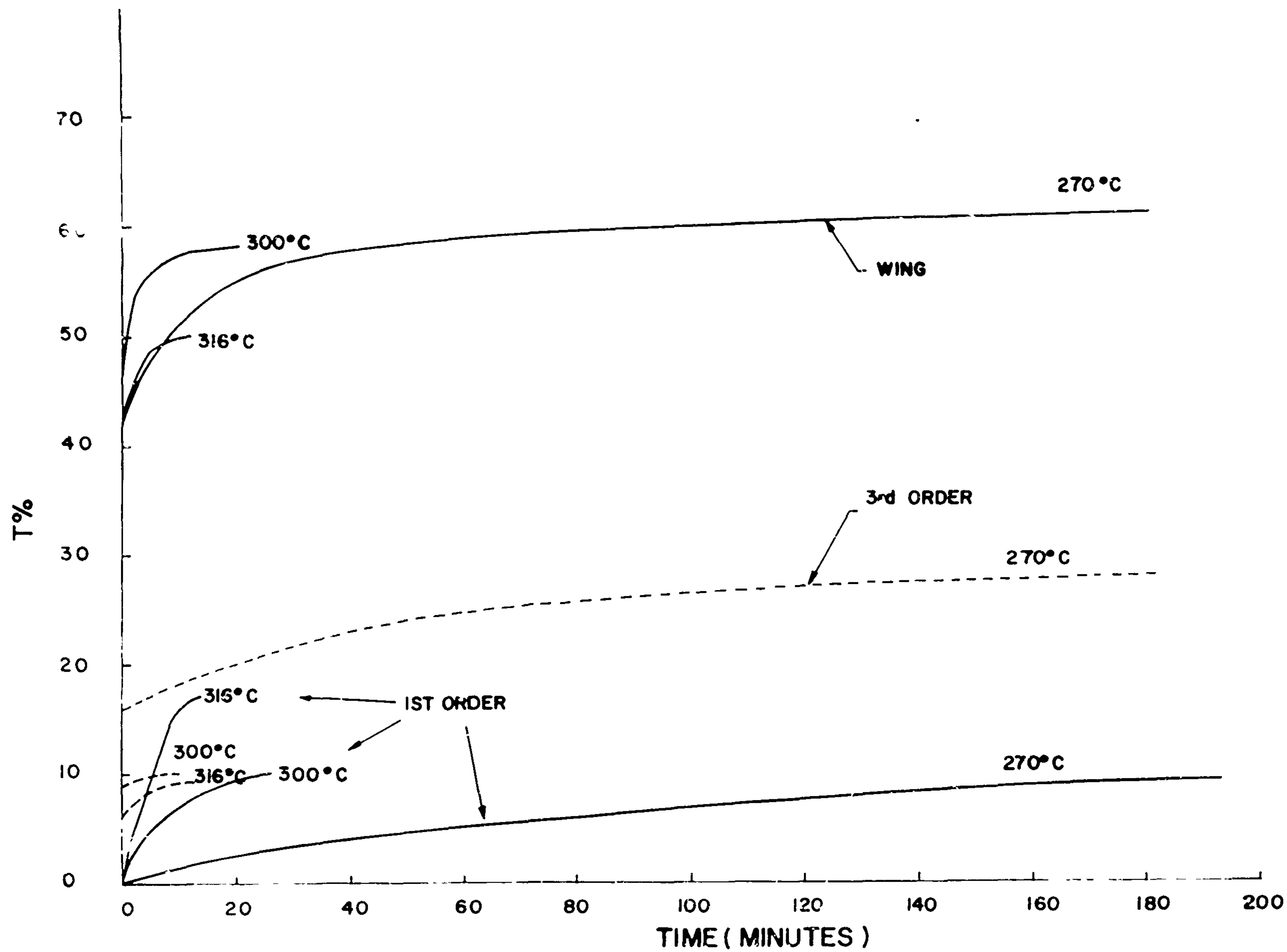


FIG. 4·41(b) F.P. INCREASED TRANSMITTANCE at VARIOUS TEMPERATURES

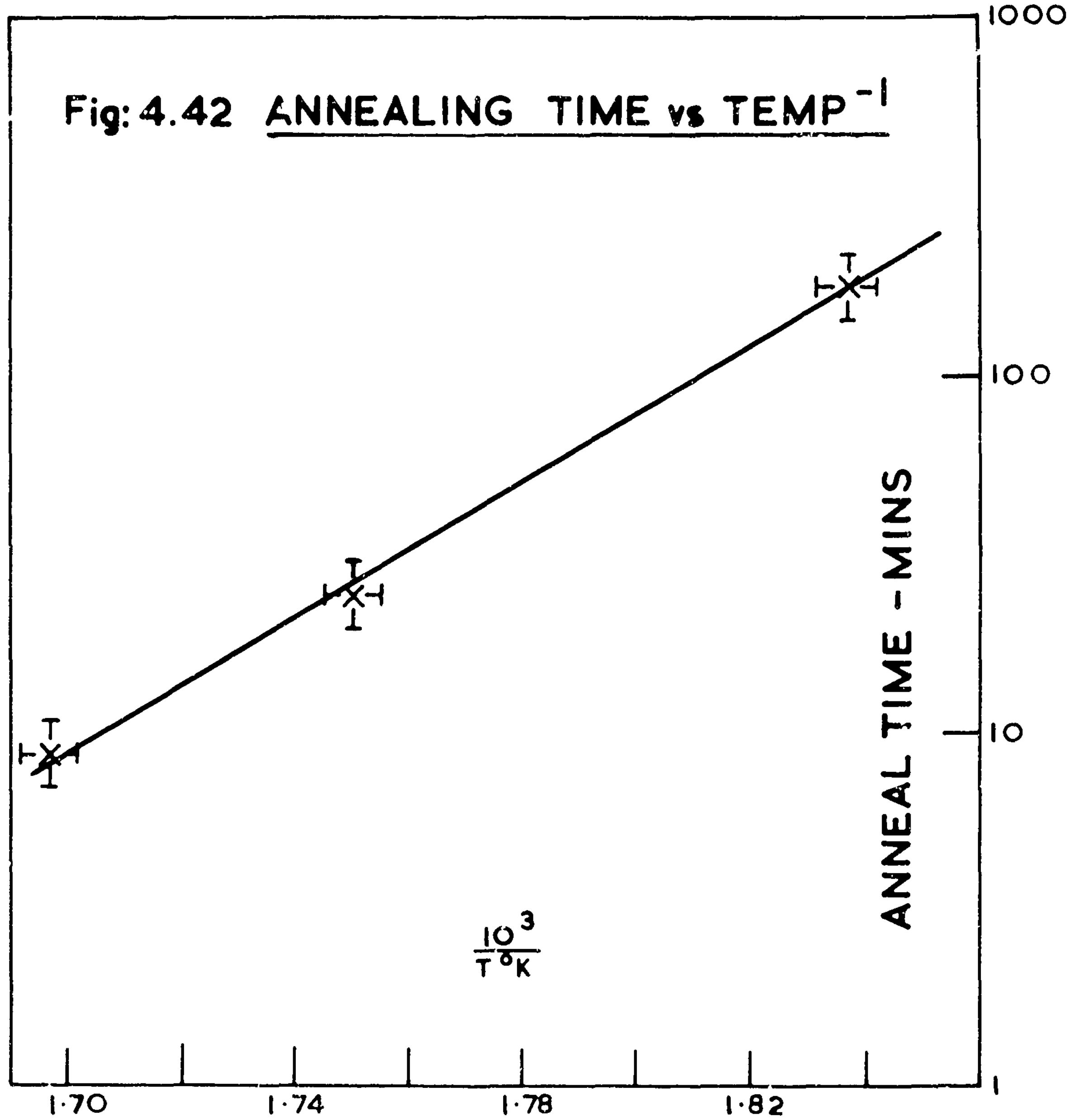


Fig: 4.42 ANNEALING TIME vs TEMP⁻¹
ANNEAL TIME - MINS
1000
100
10
1
$\frac{10^3}{T\,°K}$
1·70
1·74
1·78
1·82

Fig: 4.43 CALCULATED Ist. ORDER SHIFT vs CHANGE IN PbTe INDEX

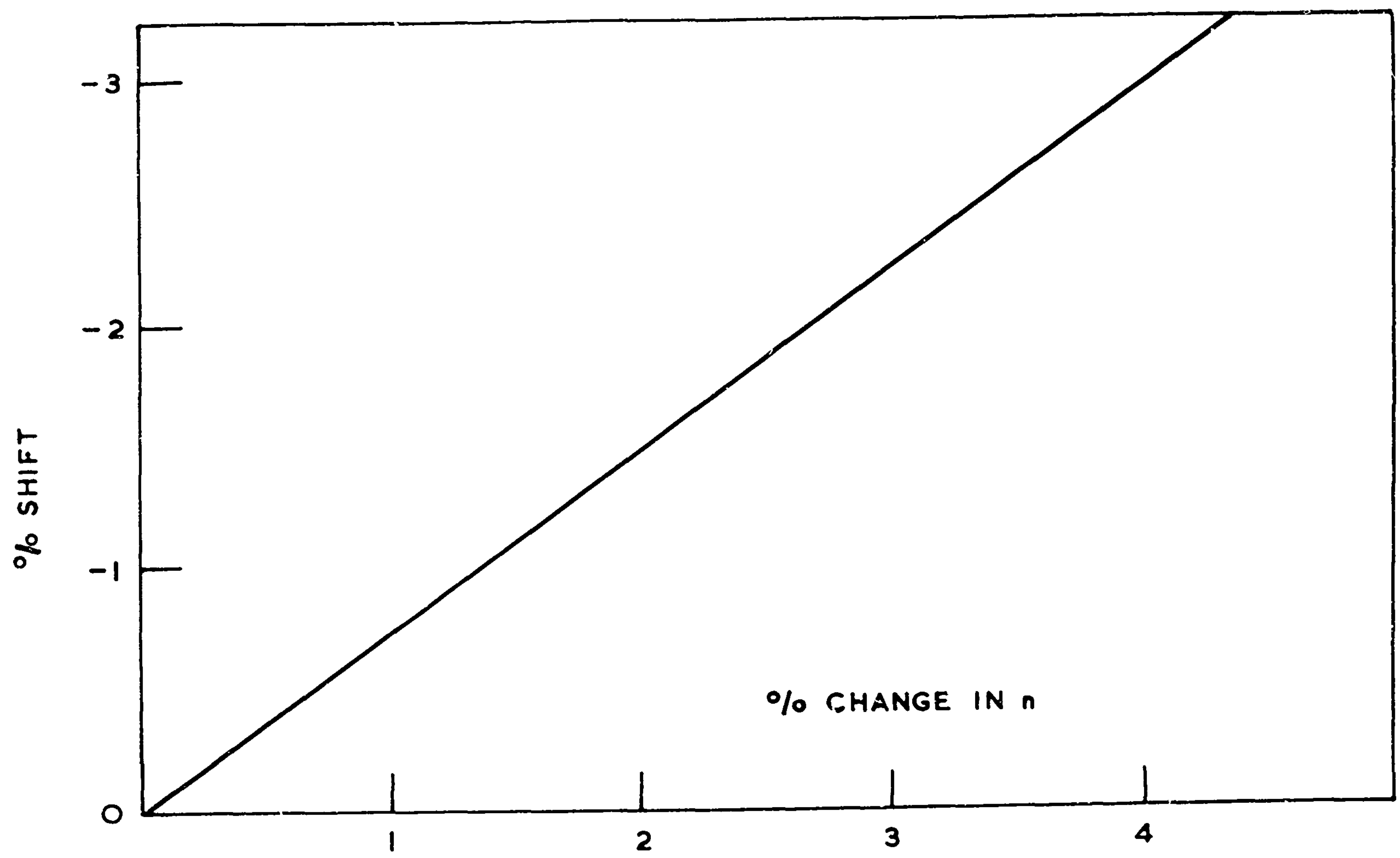
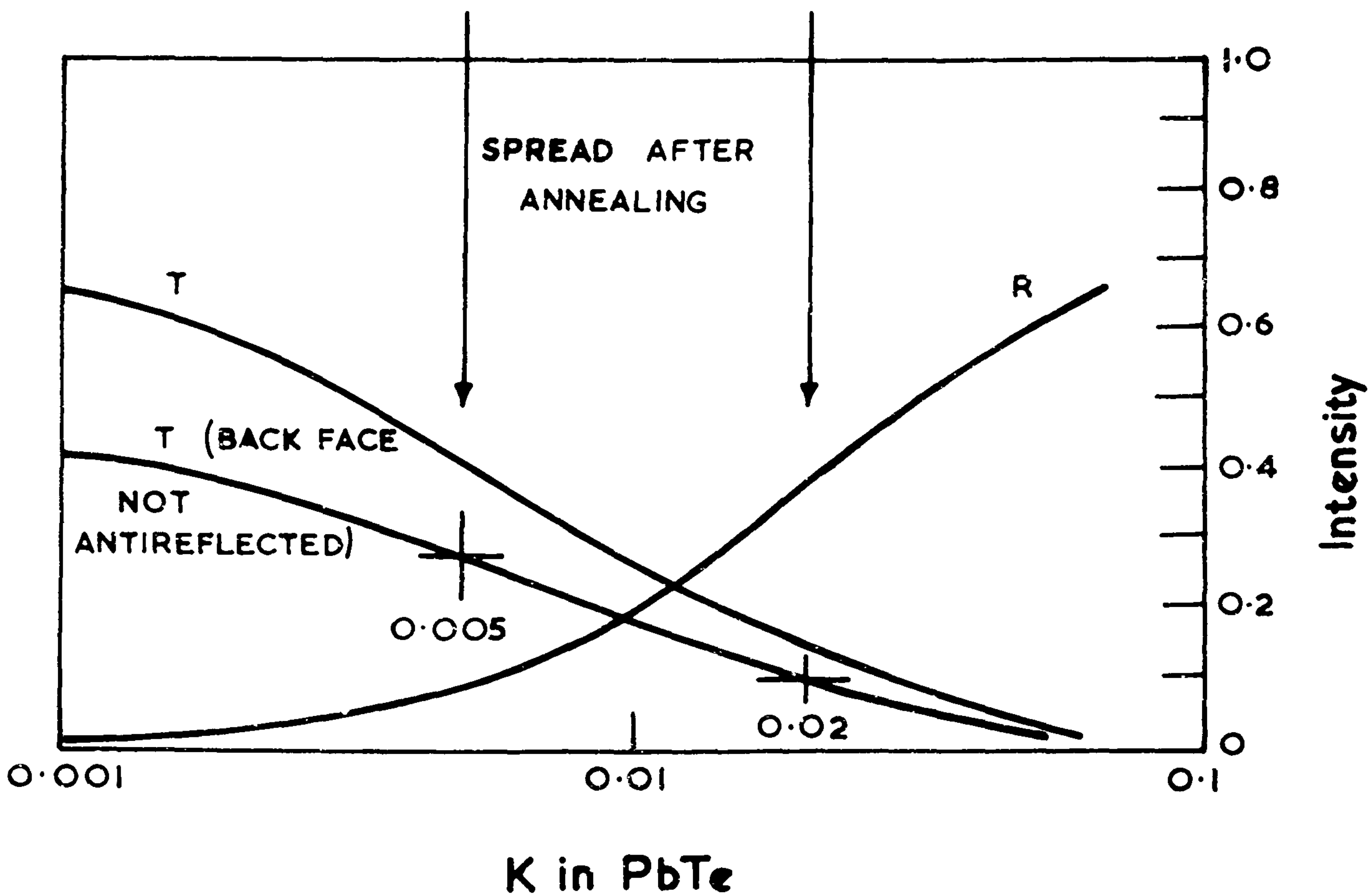


Fig: 4.44 CALCULATED TRANSMITTANCE/REFLECTANCE IN F.P. FILTER vs ABSORPTION IN PbTe



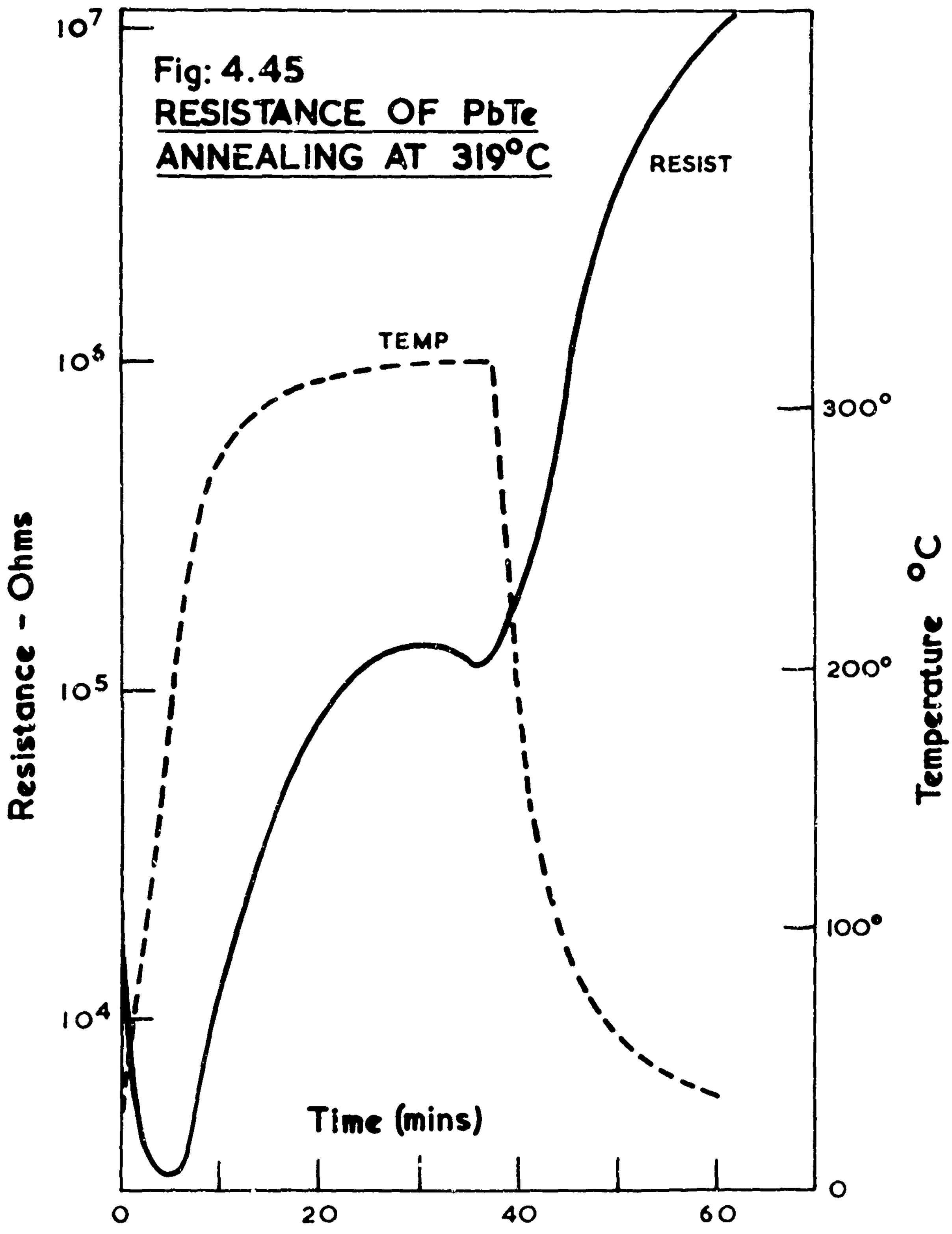


Fig: 4.45
RESISTANCE OF PbTe
ANNEALING AT 319°C
RESIST
TEMP
Resistance - Ohms
Temperature °C
Time (mins)
10^7
10^6
10^5
10^4
300°
200°
100°
0
0
20
40
60

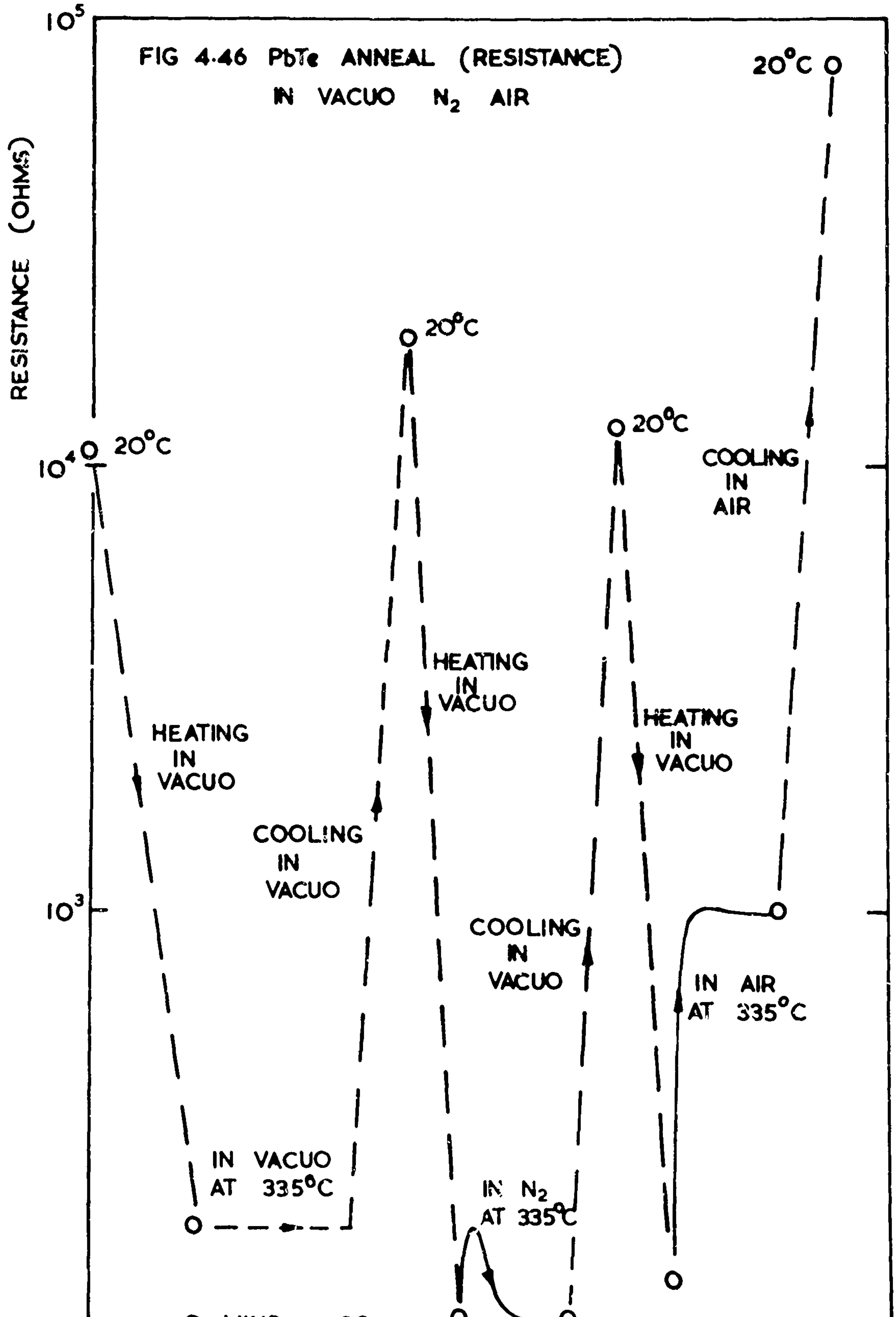


FIG 4.46 PbTe ANNEAL (RESISTANCE)
IN VACUO N2 AIR
RESISTANCE (OHMS)
10^5
10^4
10^3
10^2
20°C
HEATING IN VACUO
COOLING IN VACUO
IN VACUO AT 335°C
IN N2 AT 335°C
IN AIR AT 335°C
COOLING IN AIR
O MINS 30
O MINS 20
O MINS 20

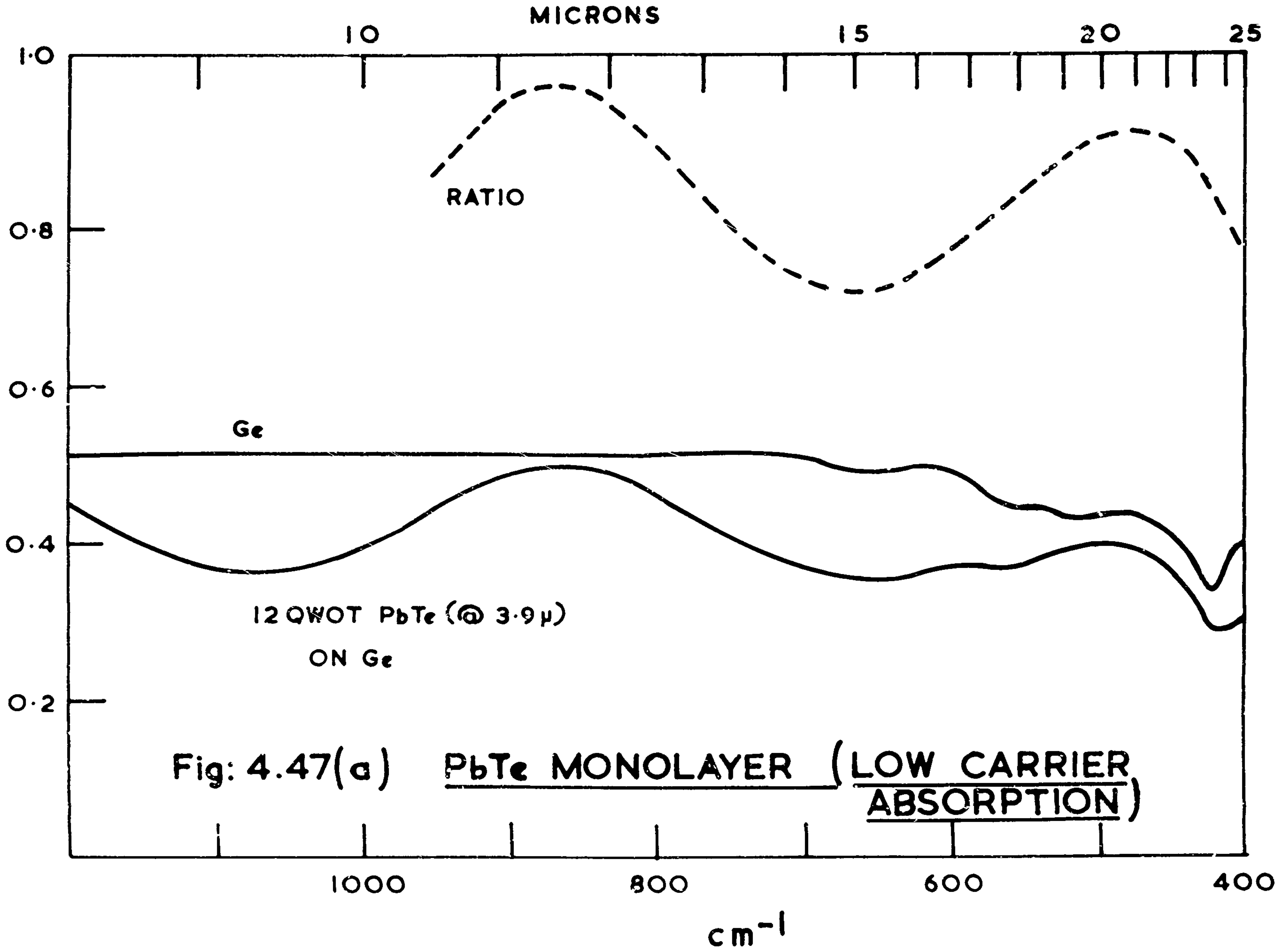


Fig: 4.47(a) PbTe MONOLAYER (LOW CARRIER ABSORPTION)

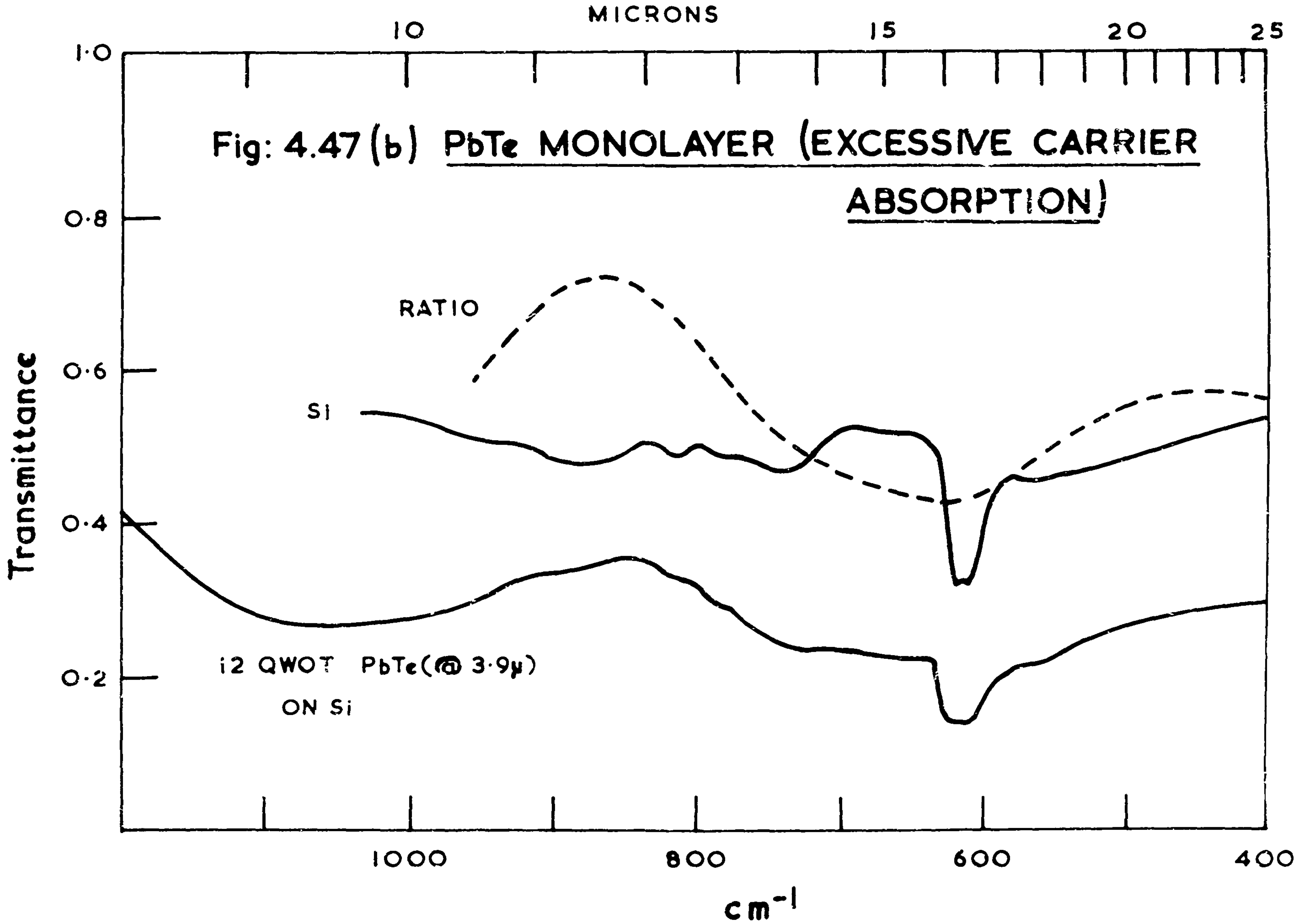


Fig: 4.47 (b) PbTe MONOLAYER (EXCESSIVE CARRIER ABSORPTION)

FIG 4.48 a DISPERSION CURVES FOR PbTe FOR VARIOUS NO OF CARRIERS

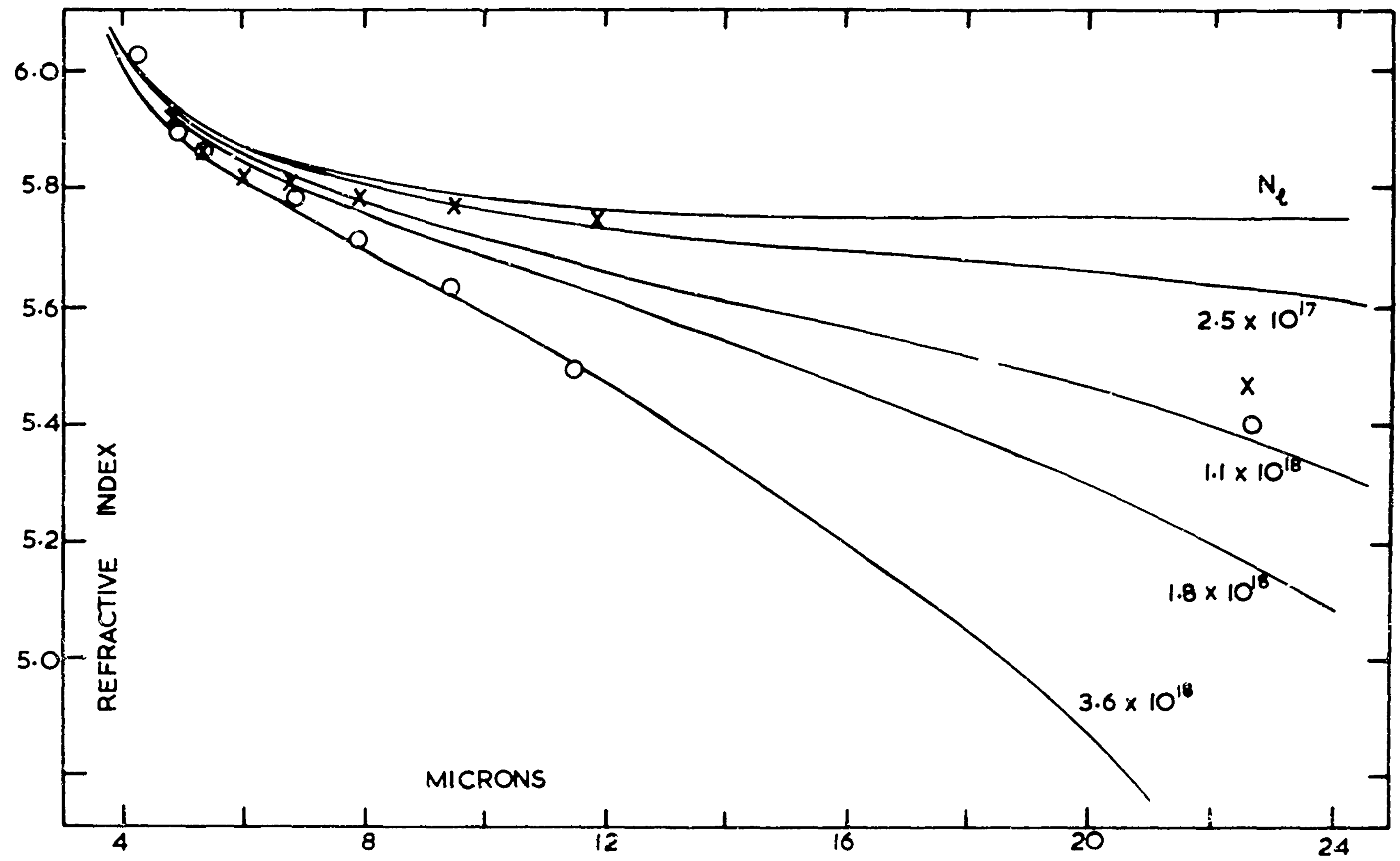
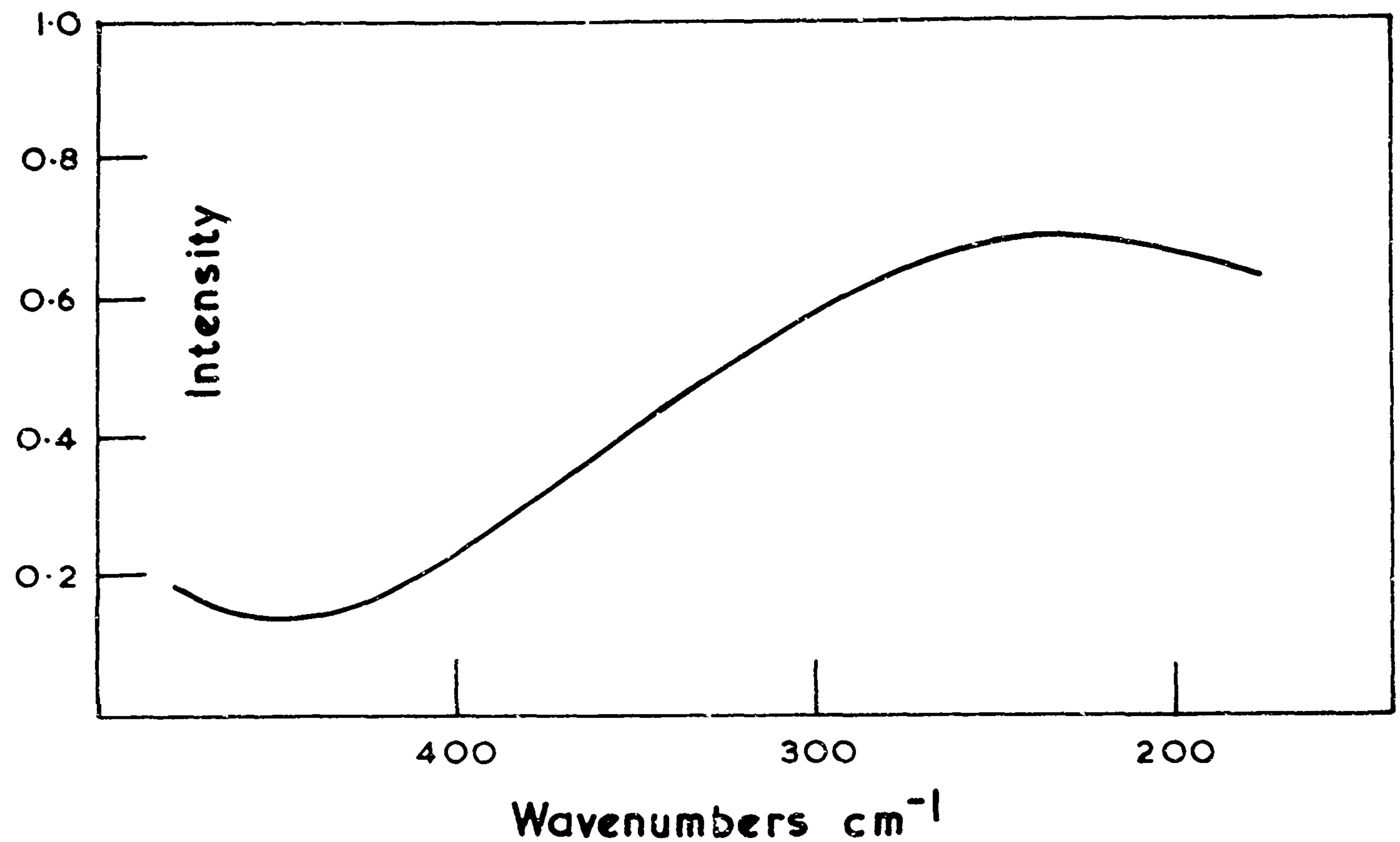


Fig:4.48(b) REFLECTANCE OF PbTe MONOLAYER
(AS FRACTION OF REFLECTANCE OF Si MIRROR)



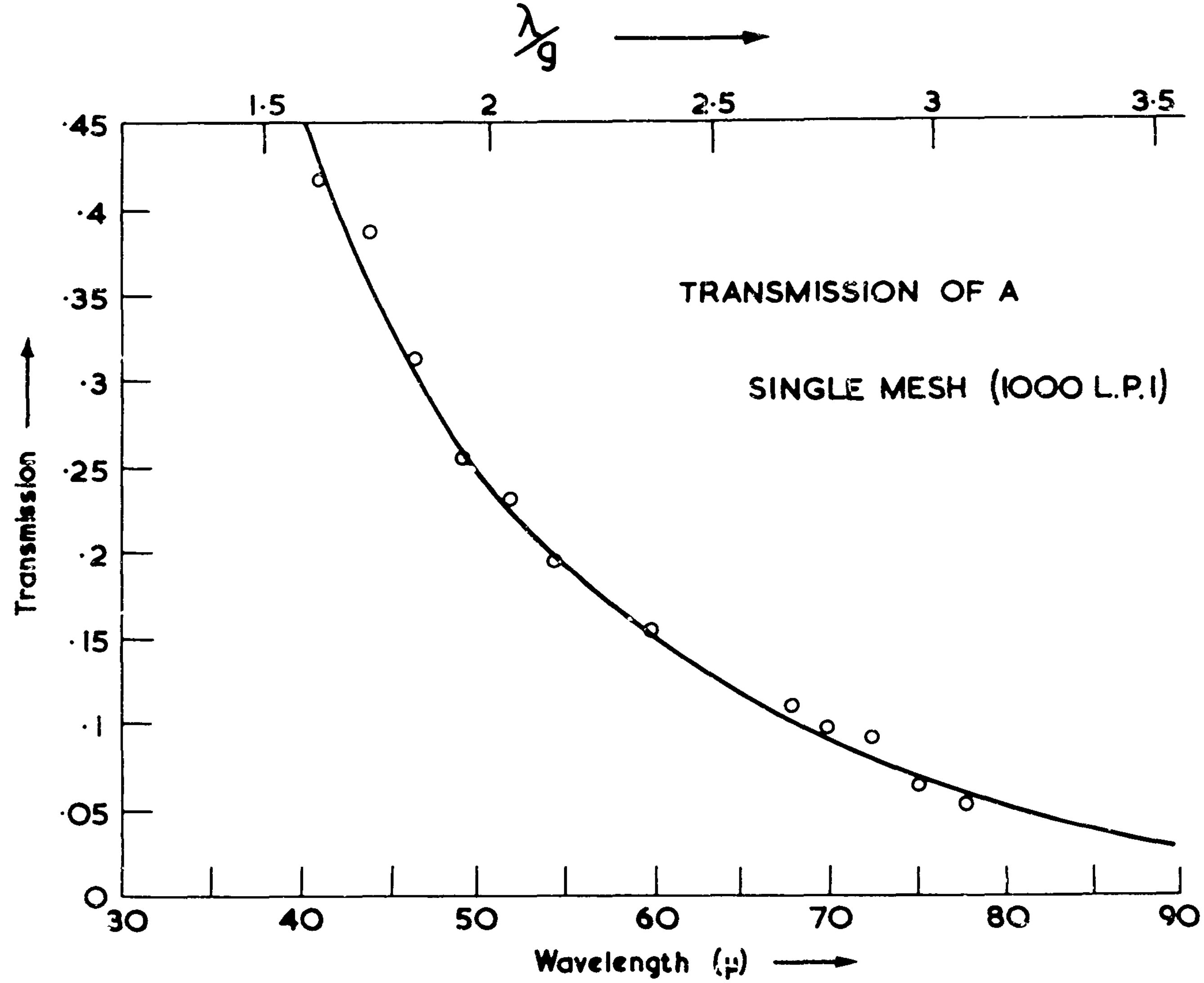
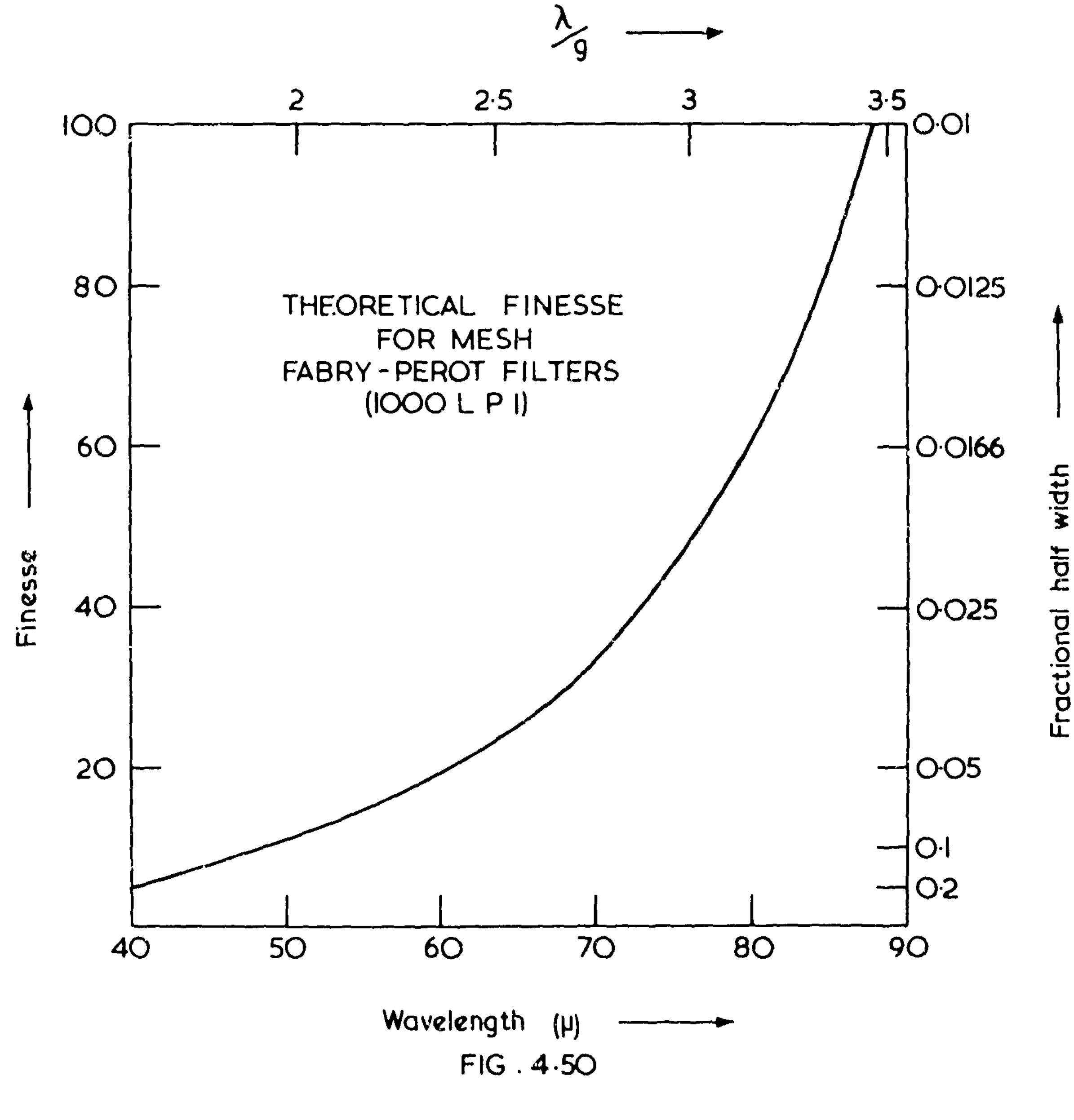

λ/g
1·5
2
2·5
3
3·5
·45
·4
·35
·3
·25
·2
·15
·1
·05
0
Transmission
TRANSMISSION OF A
SINGLE MESH (1000 L.P.I)
30
40
50
60
70
80
90
Wavelength (μ)

FIG. 4·49



λ/g
2
2·5
3
3·5
100
80
60
40
20
0·01
0·0125
0·0166
0·025
0·05
0·1
0·2
THEORETICAL FINESSE
FOR MESH
FABRY - PEROT FILTERS
(1000 L P I)
Finesse
Fractional half width
40
50
60
70
80
90
Wavelength (μ)

FIG . 4·50

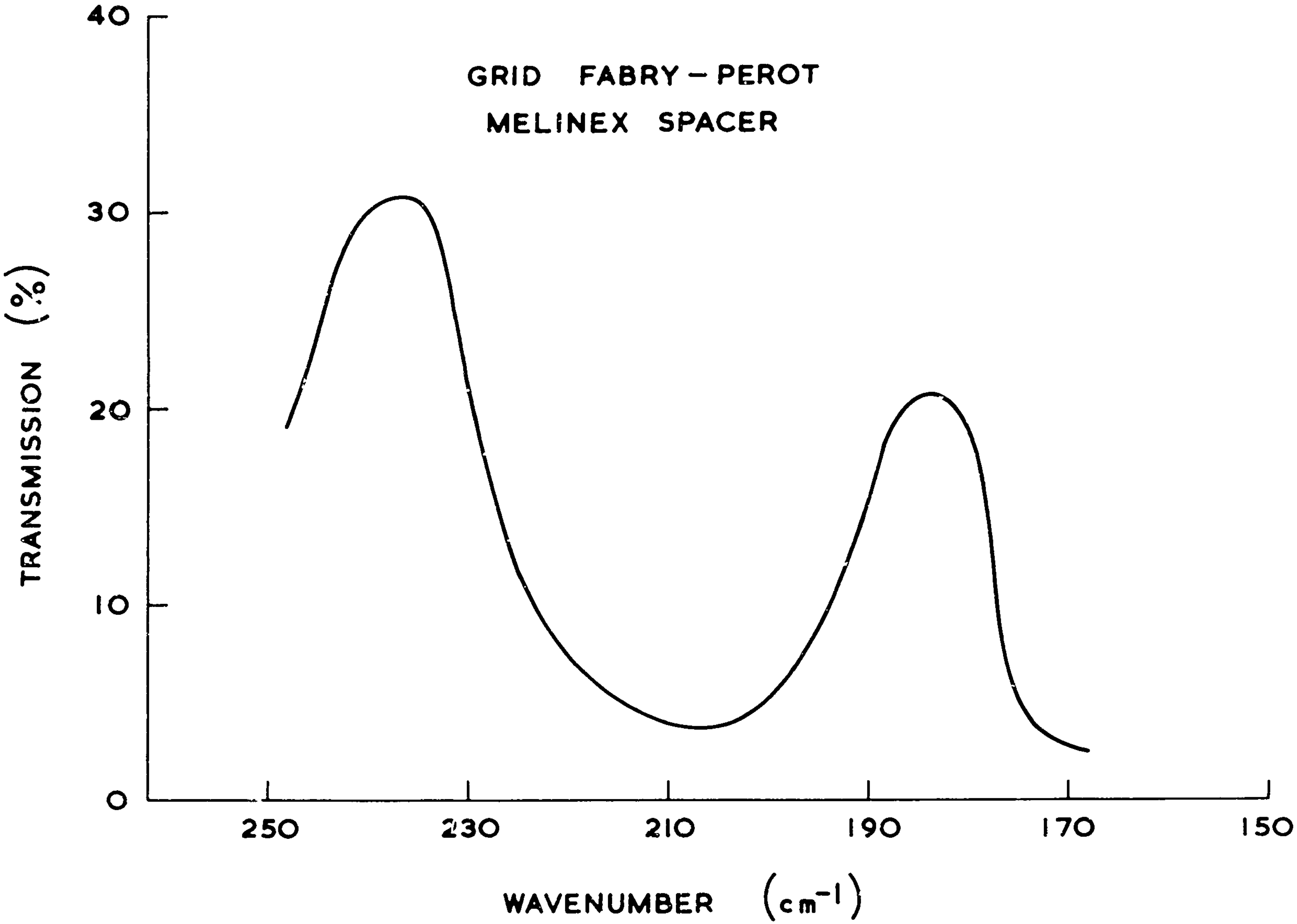

GRID FABRY – PEROT
MELINEX SPACER
TRANSMISSION (%)
40
30
20
10
0
250
230
210
190
170
150
WAVENUMBER (cm⁻¹)

FIG. 4.51

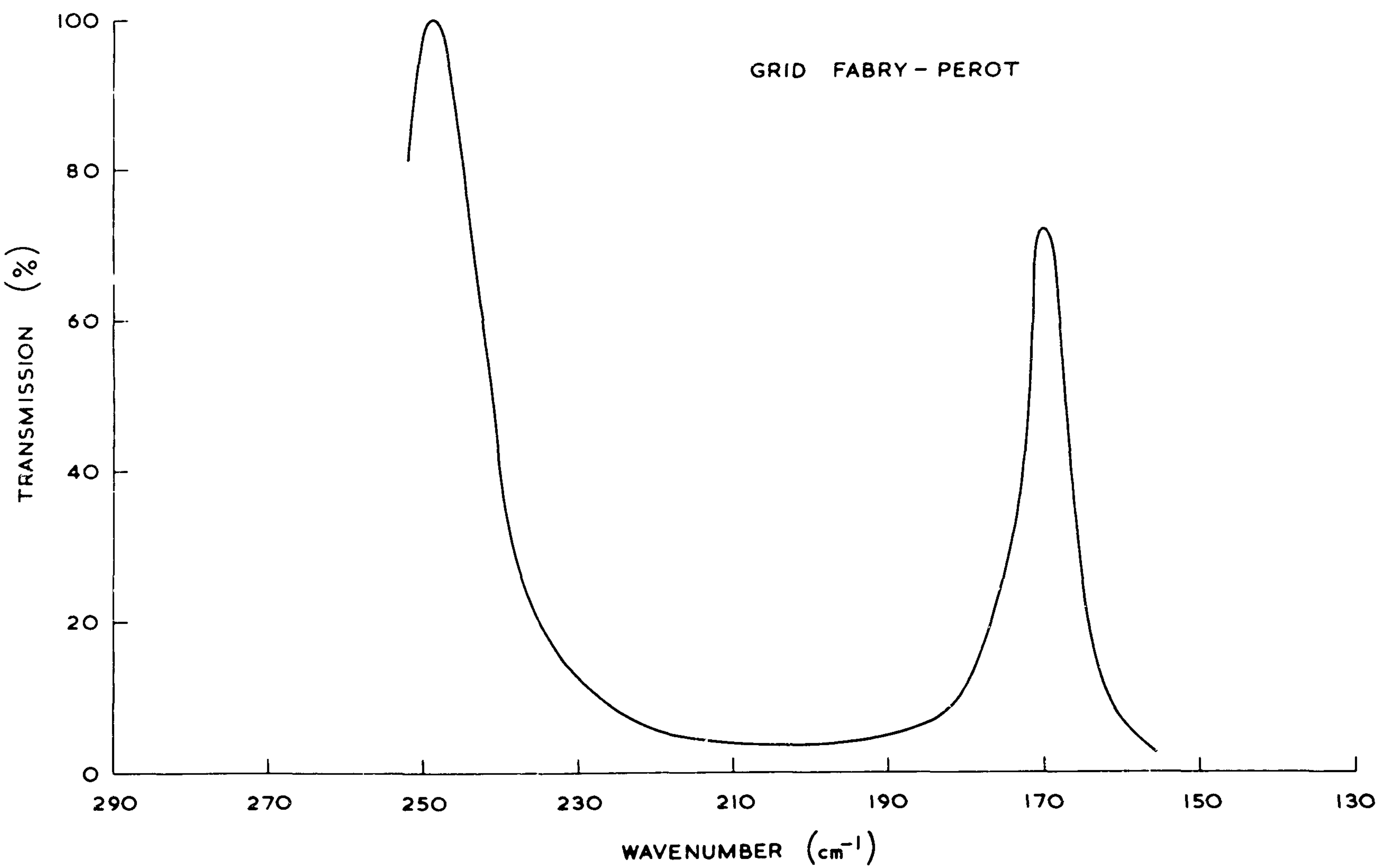

GRID FABRY - PEROT
TRANSMISSION (%)
100
80
60
40
20
0
290
270
250
230
210
190
170
150
130
WAVENUMBER (cm⁻¹)

FIG. 4·52

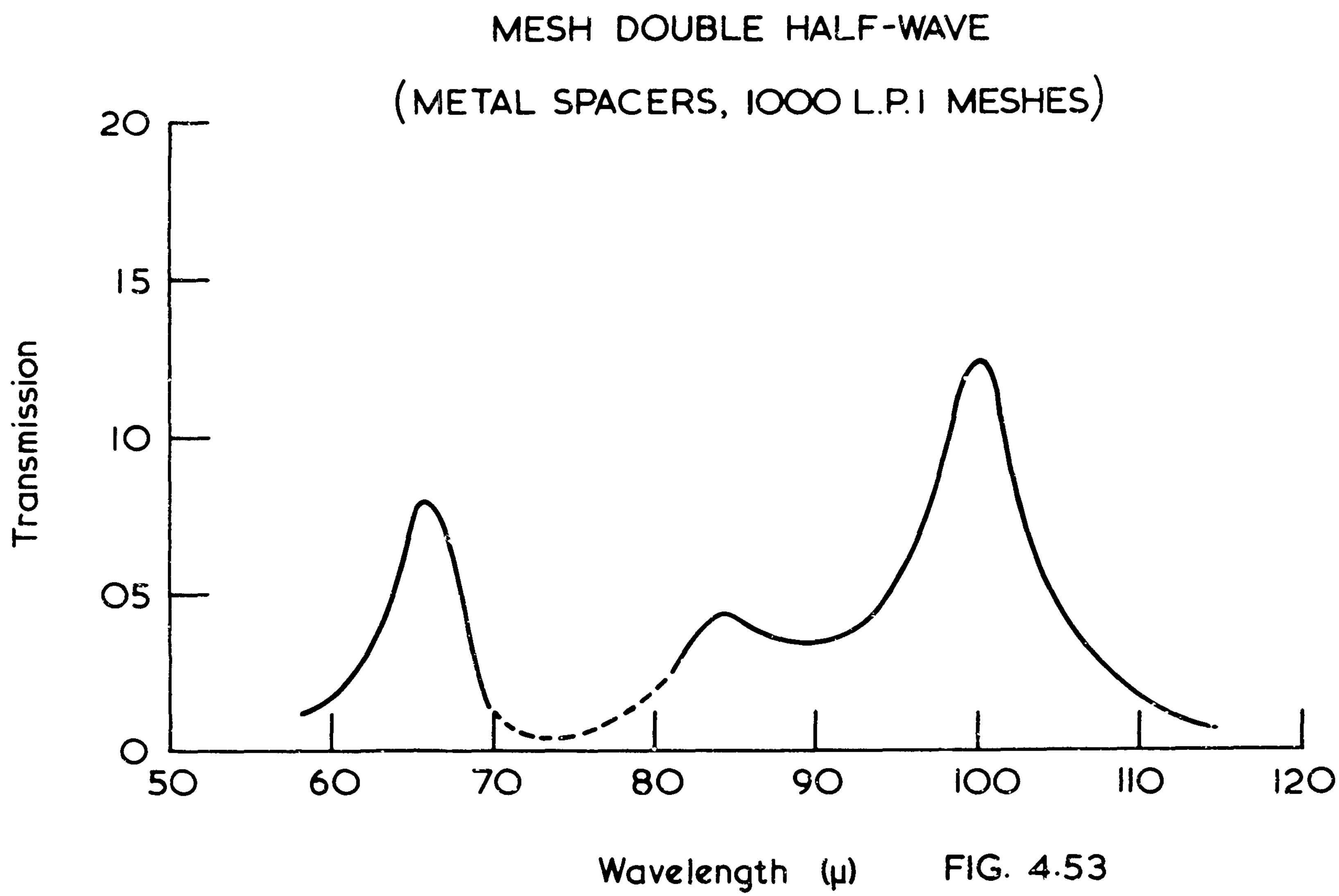

MESH DOUBLE HALF-WAVE
(METAL SPACERS, 1000 L.P.I MESHES)
Transmission
20
15
10
05
0
50
60
70
80
90
100
110
120
Wavelength (μ)

FIG. 4.53

FILTER FABRICATION—EXPLODED VIEW

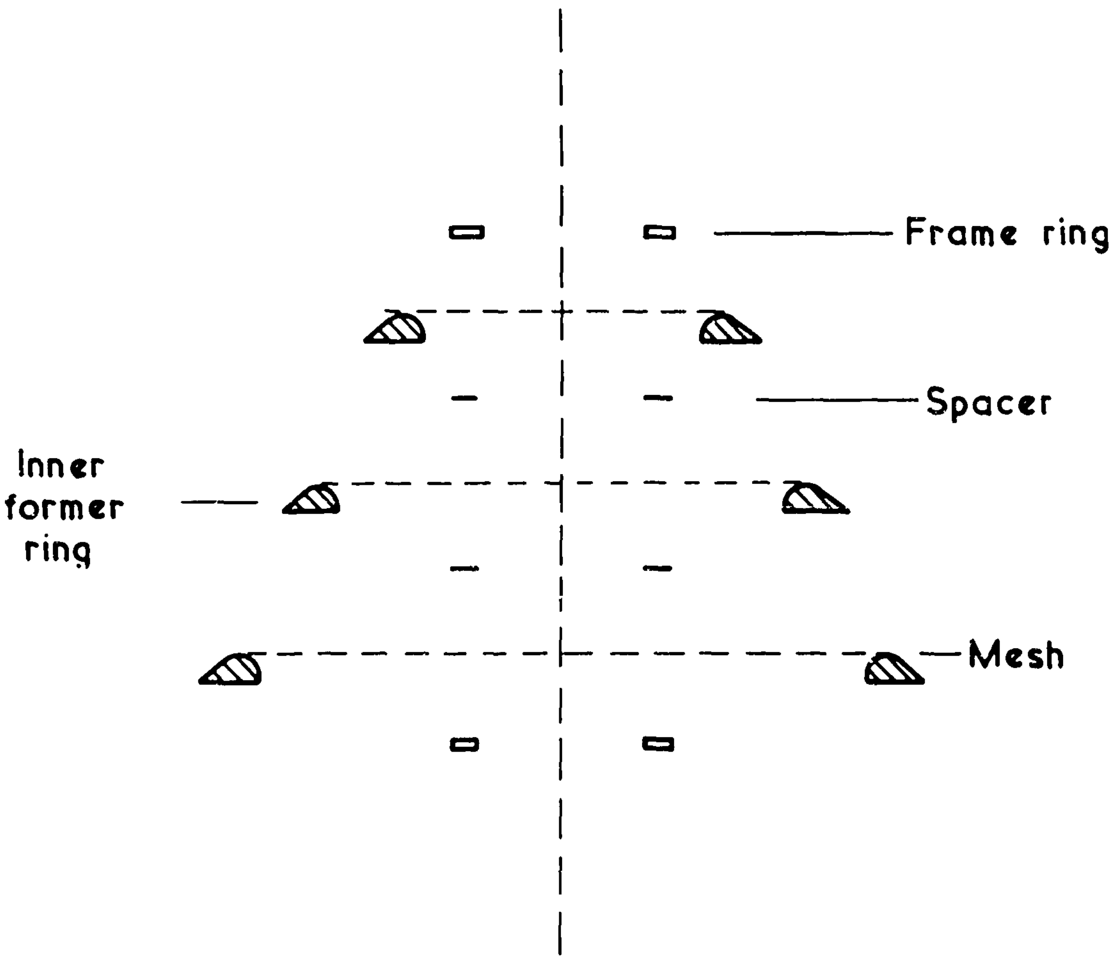


FIG. 4·54

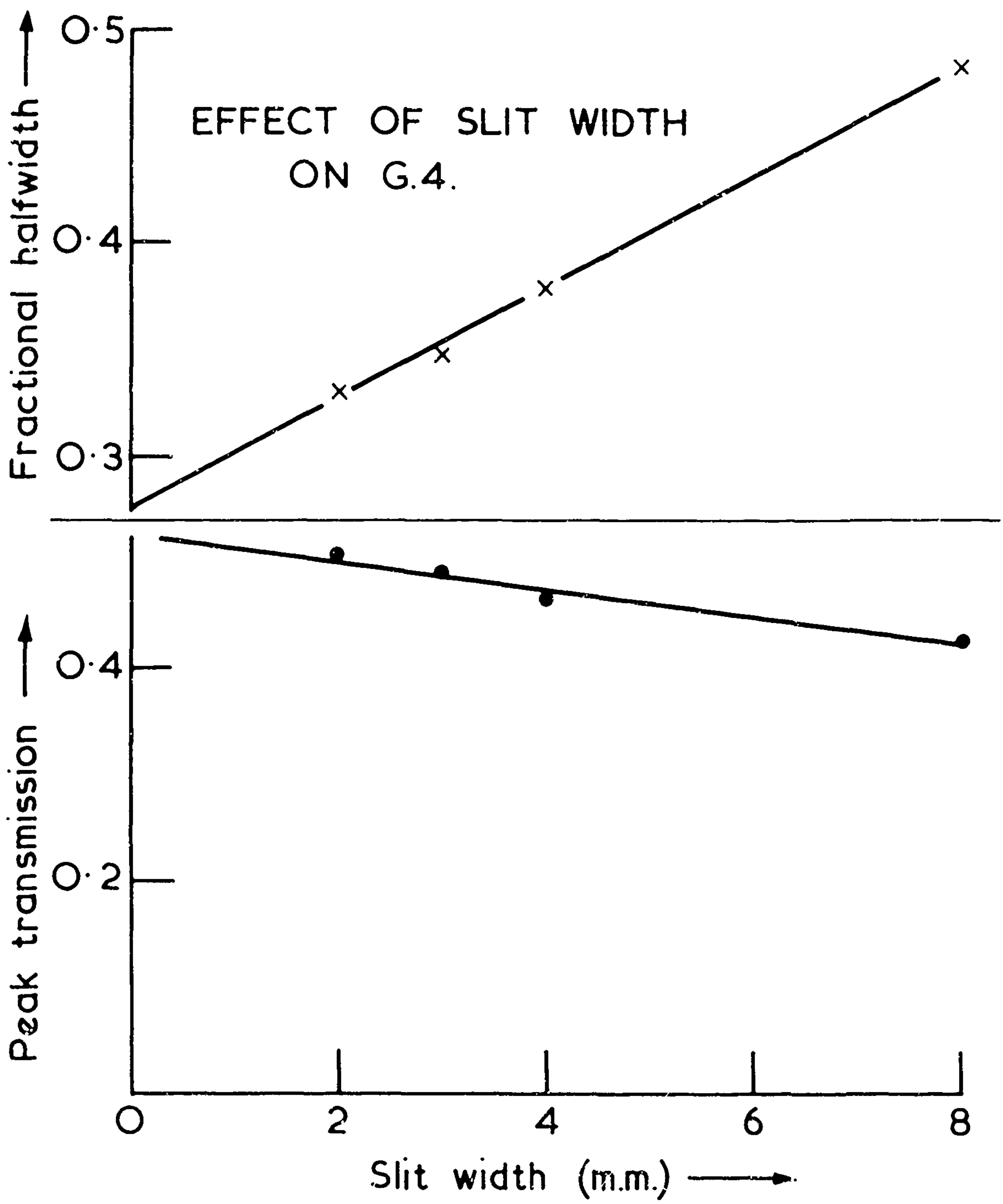
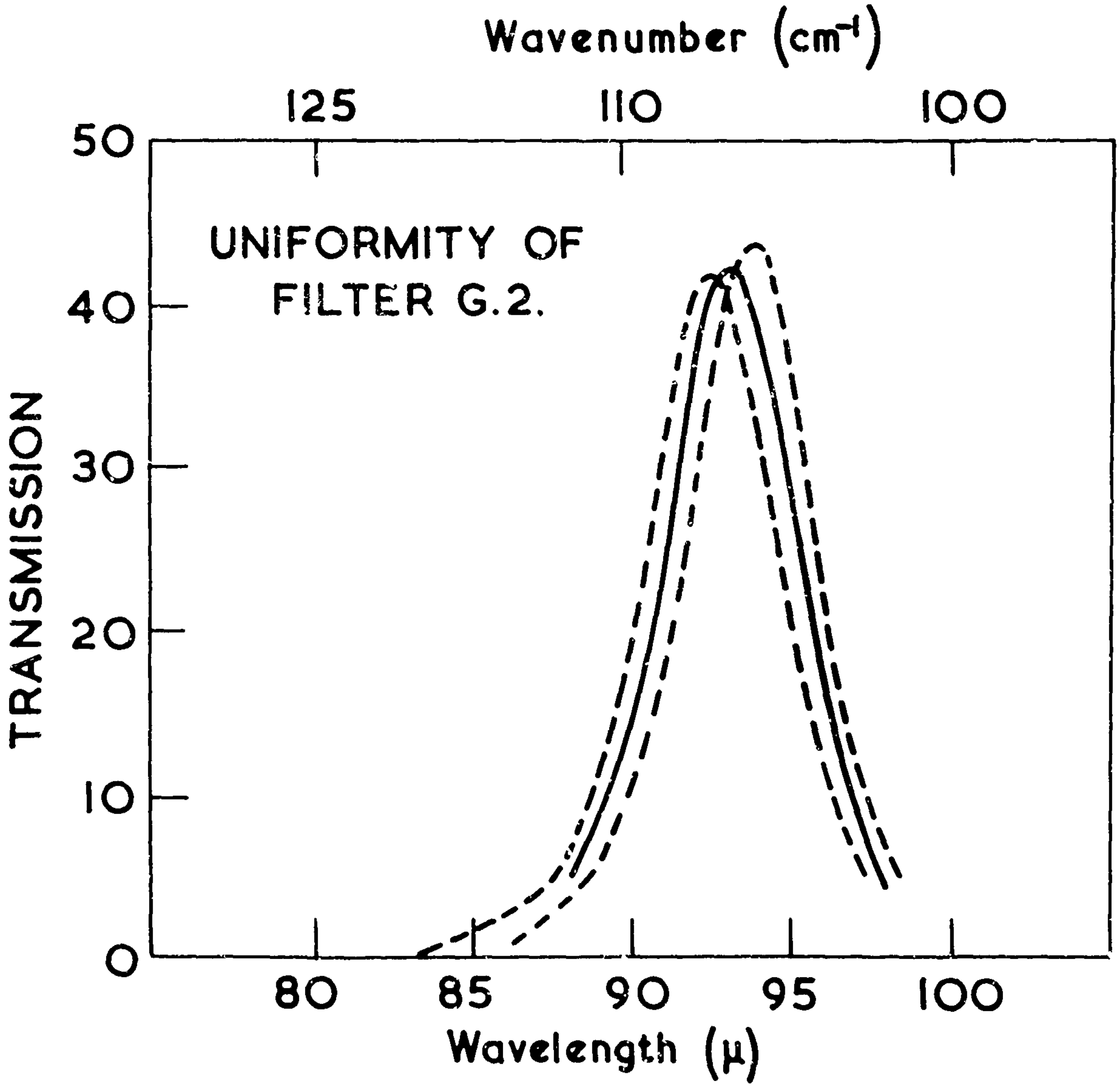

EFFECT OF SLIT WIDTH
ON G.4.
Fractional halfwidth
0·5
0·4
0·3
Peak transmission
0·4
0·2
0
2
4
6
8
Slit width (m.m.)

FIG. 4.55



Wavenumber (cm⁻¹)
125
110
100
50
40
30
20
10
0
UNIFORMITY OF
FILTER G.2.
TRANSMISSION
80
85
90
95
100
Wavelength (μ)

FIG. 4·56

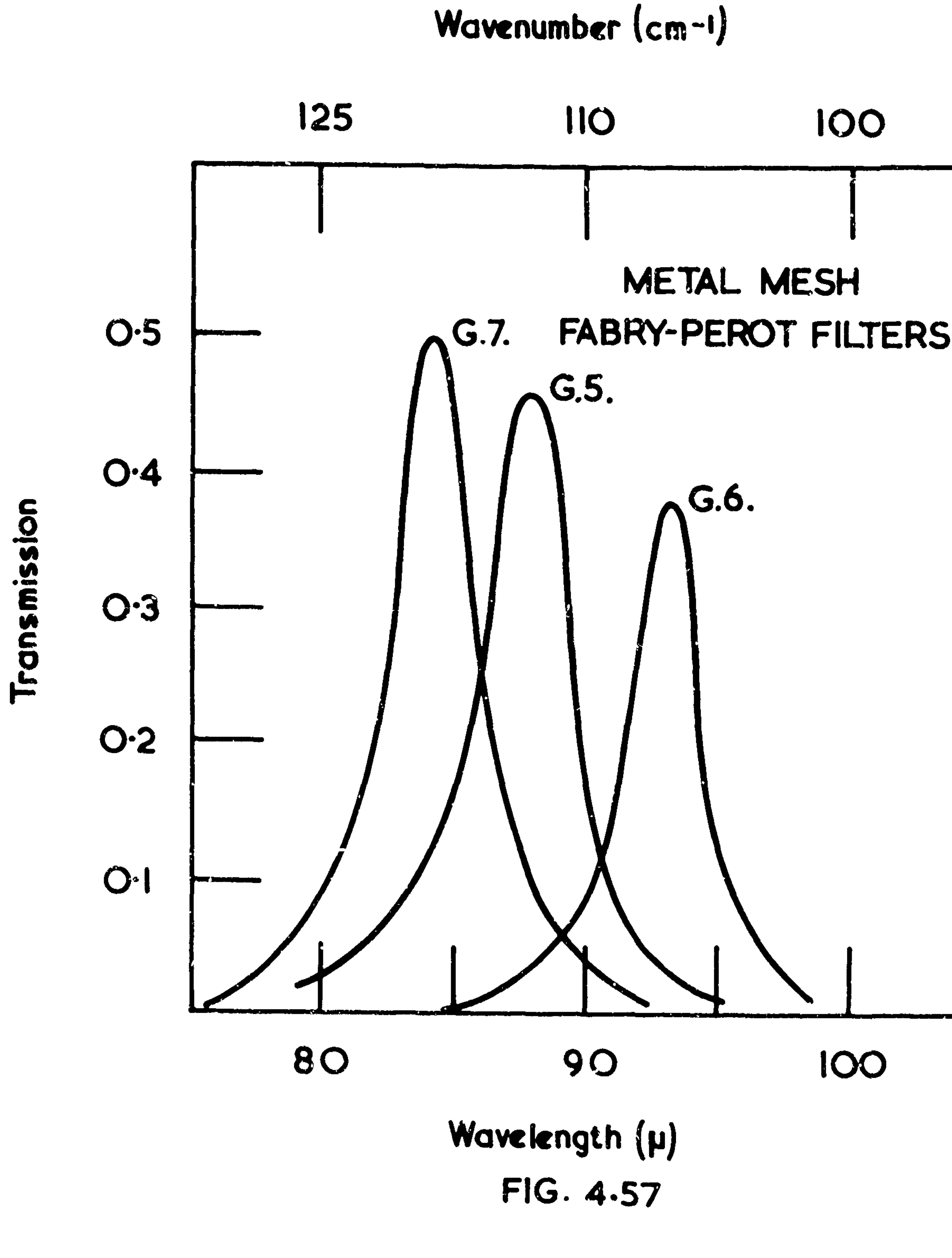

Wavenumber (cm⁻¹)
125
110
100
METAL MESH
FABRY-PEROT FILTERS
G.7.
G.5.
G.6.
0·5
0·4
0·3
0·2
0·1
Transmission
80
90
100
Wavelength (μ)

FIG. 4.57

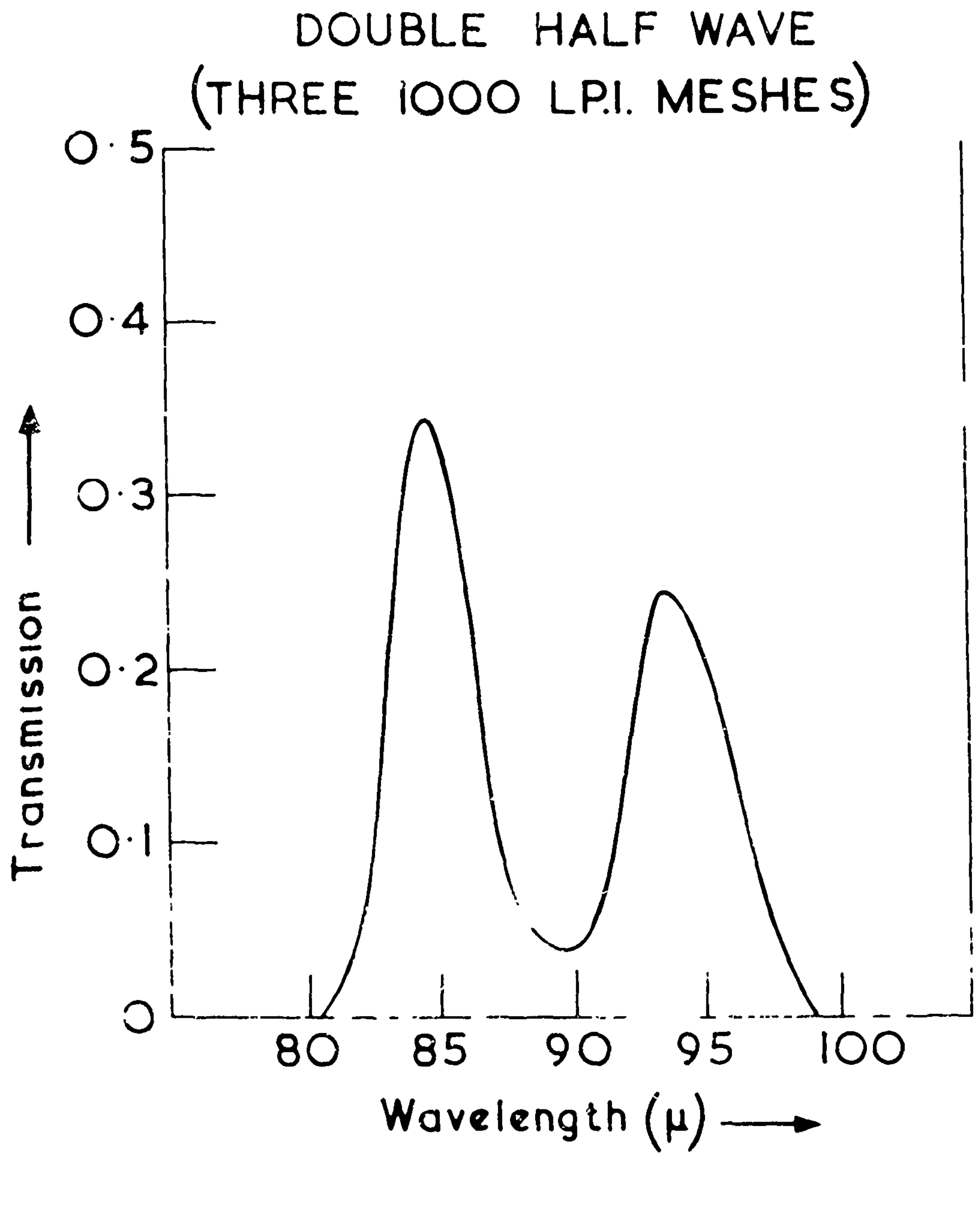

DOUBLE HALF WAVE
(THREE 1000 L.P.I. MESHES)
0·5
0·4
0·3
0·2
0·1
0
Transmission
80
85
90
95
100
Wavelength (μ)

FIG. 4·58

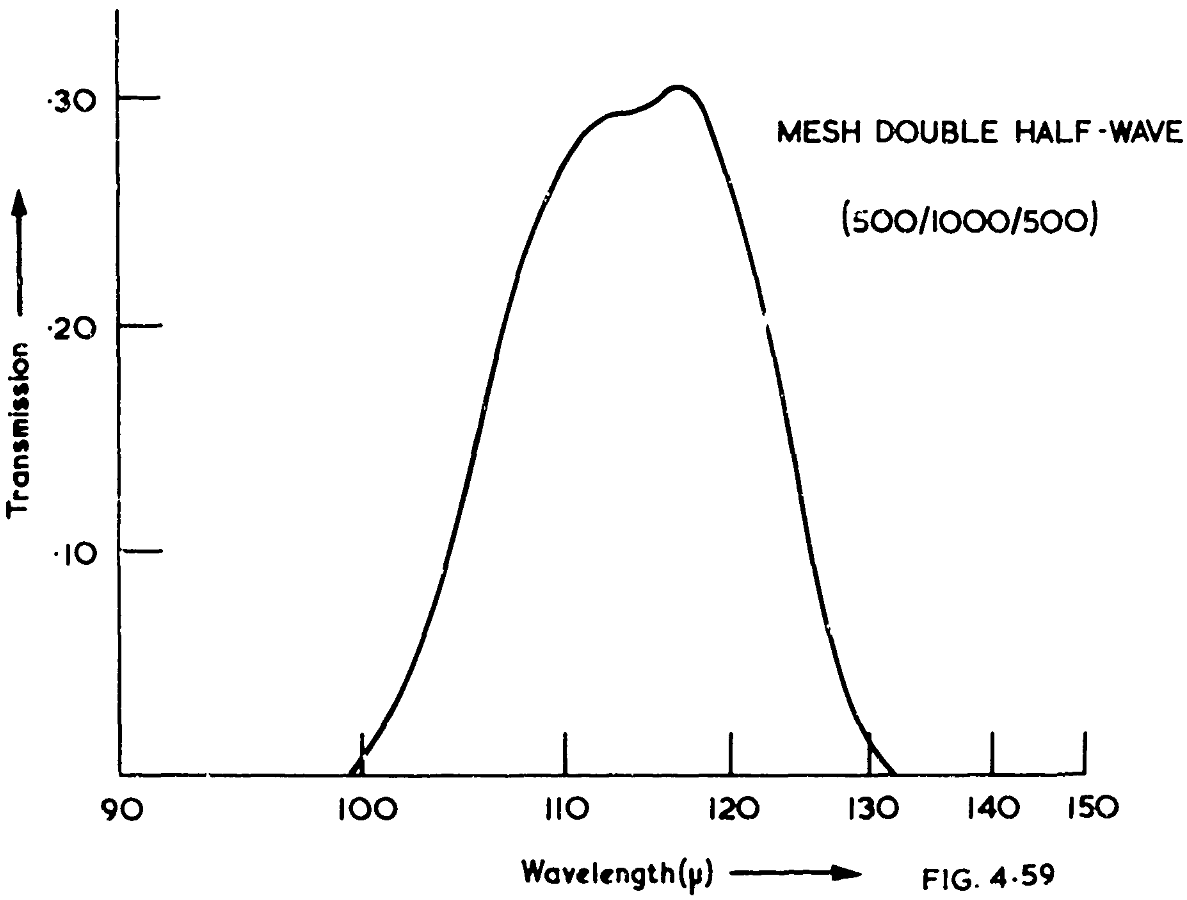
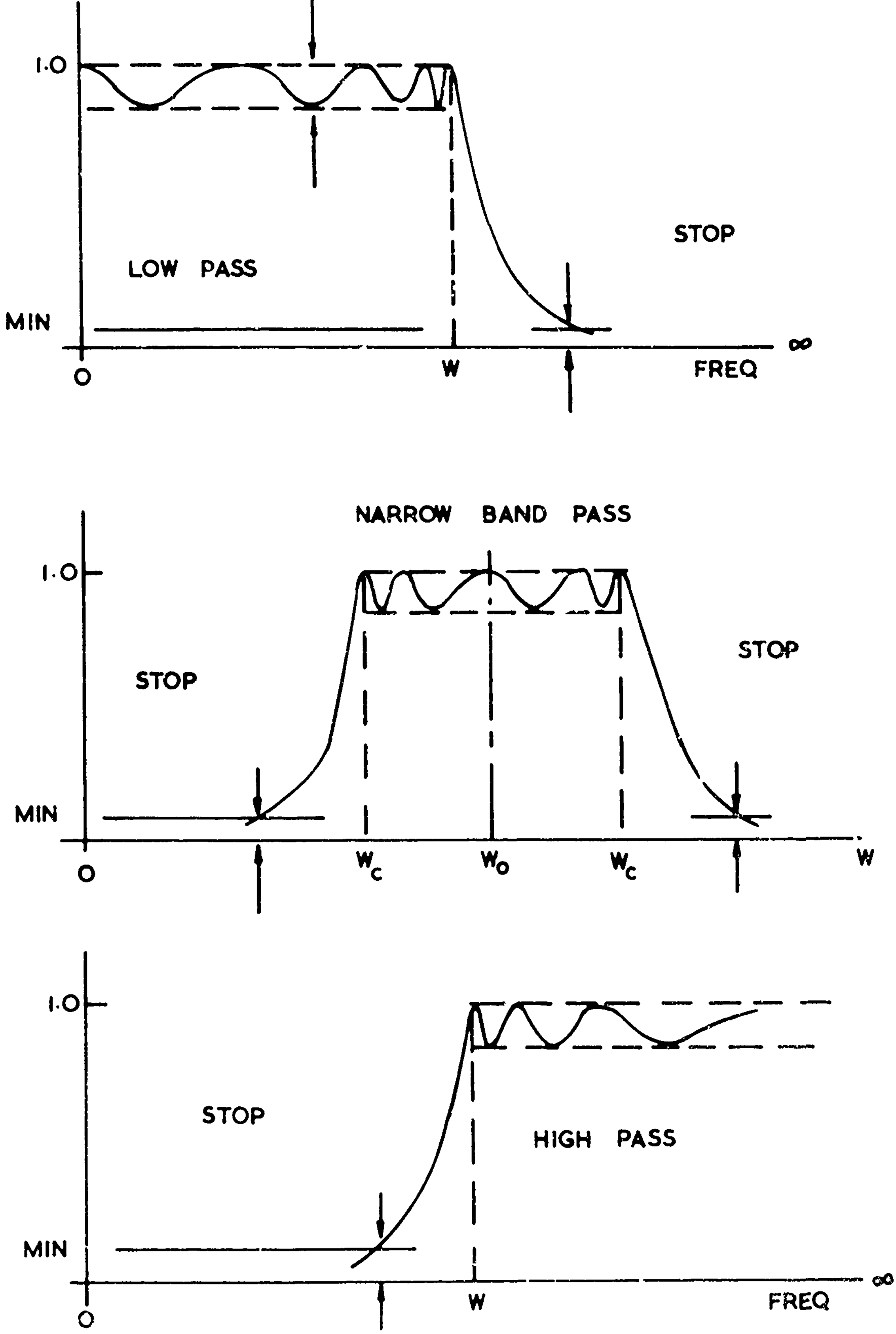

MESH DOUBLE HALF-WAVE
(500/1000/500)
Transmission
·30
·20
·10
90
100
110
120
130
140
150
Wavelength(μ)

FIG. 4·59

FIG 5.1 IDEALISED FILTER CHARACTERISTICS



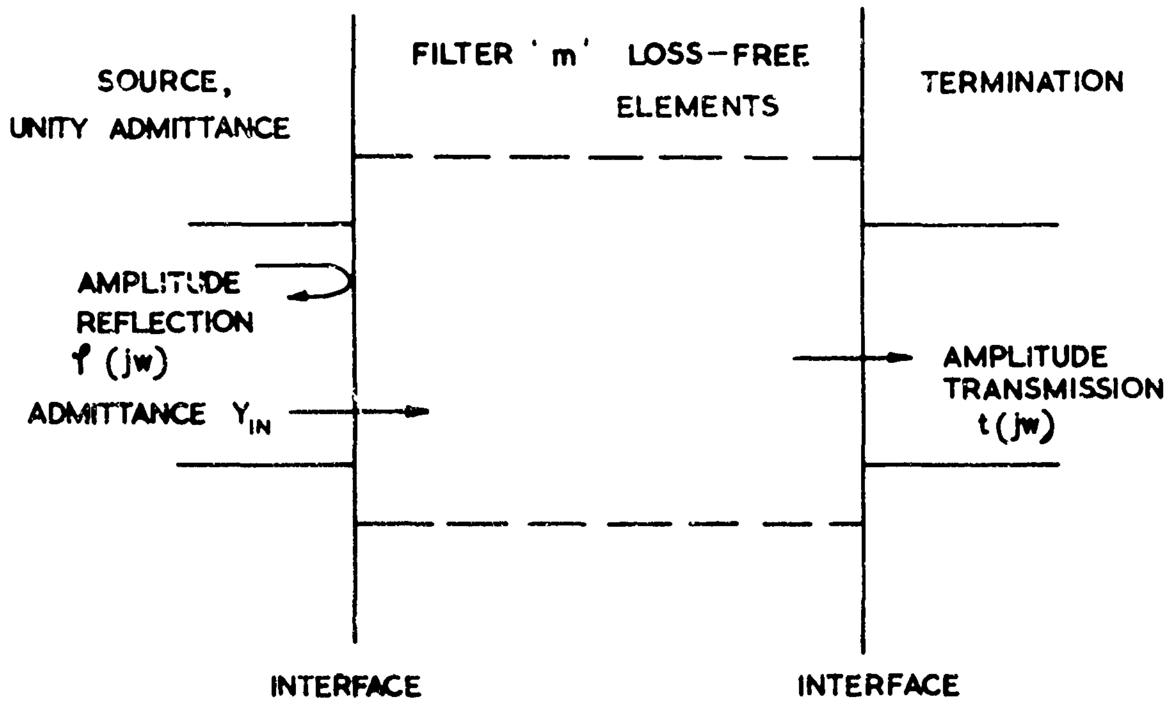


FIG 5.2 INTERFACE DESCRIPTION

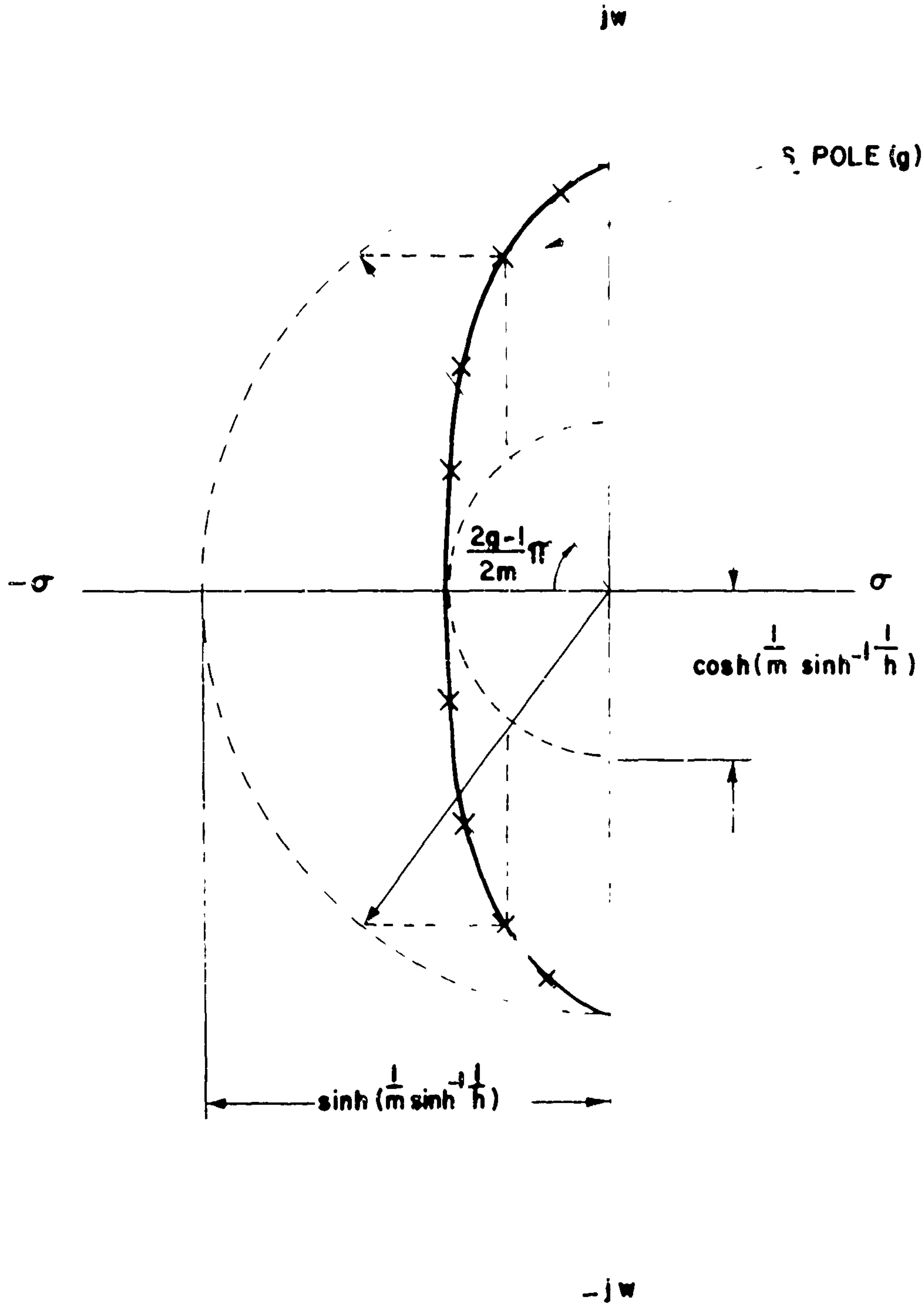
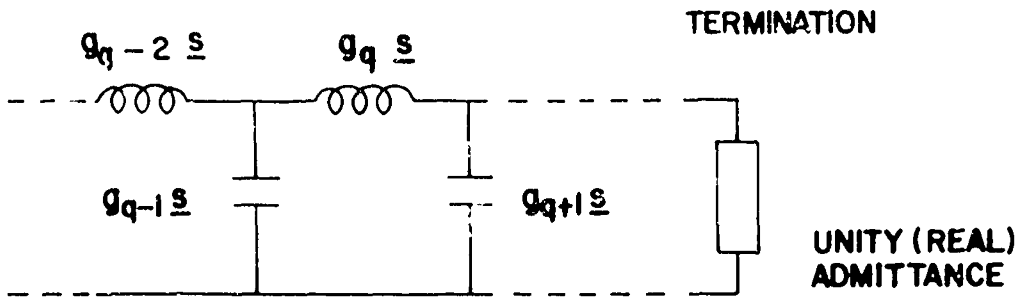


FIG. 5·3 S – PLANE LOCUS AND CONSTRUCTION



IN FIG.5·3,

$$\underline{s}\ \text{POLE}(q) = -\sin\frac{(2q-1)\pi}{2m}\,\sinh\left(m^{-1}\sinh^{-1}\frac{1}{h}\right) + j\cos\frac{(2q-1)\pi}{2m}\,\cosh\left(m^{-1}\sinh^{-1}\frac{1}{h}\right) \qquad \text{ETC.}$$

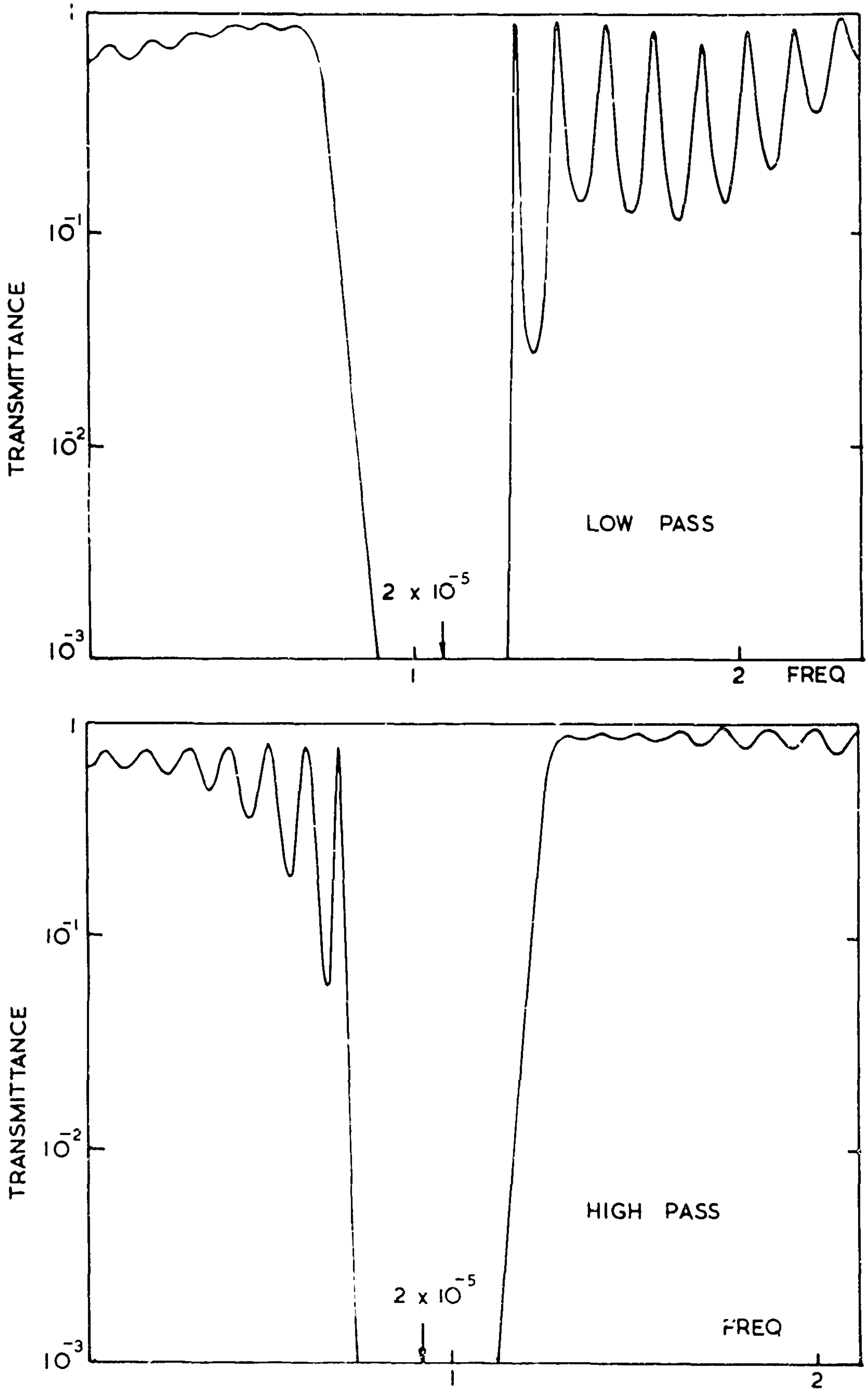
FOR the SIMPLEST LOW PASS EQUIVALENT CIRCUIT (as SHOWN) IMPEDANCE is GIVEN for SERIES ELEMENTS, ADMITTANCE for SHUNT ELEMENTS,

$$\text{WHERE } q_1 = \frac{2\sin\frac{\pi}{2m}}{\sinh\left(\frac{1}{m}\sinh^{-1}\frac{1}{h}\right)}$$

$$g_{q-1}\,g_q = \frac{4\sin\frac{(2q-1)\pi}{2m}\,\sin\frac{(2q+1)\pi}{2m}}{\sinh^2\left(\frac{1}{m}\sinh^{-1}\frac{1}{h}\right)+\sin^2\frac{q\pi}{m}} \qquad \text{ETC.}$$

FIG.5·4 TCHEBYSHEV CIRCUIT PARAMETERS

FIG 5 5 COMPUTED TCHEBYSHEV FILTERS
(PARAMETERS IN TABLE 5.1)



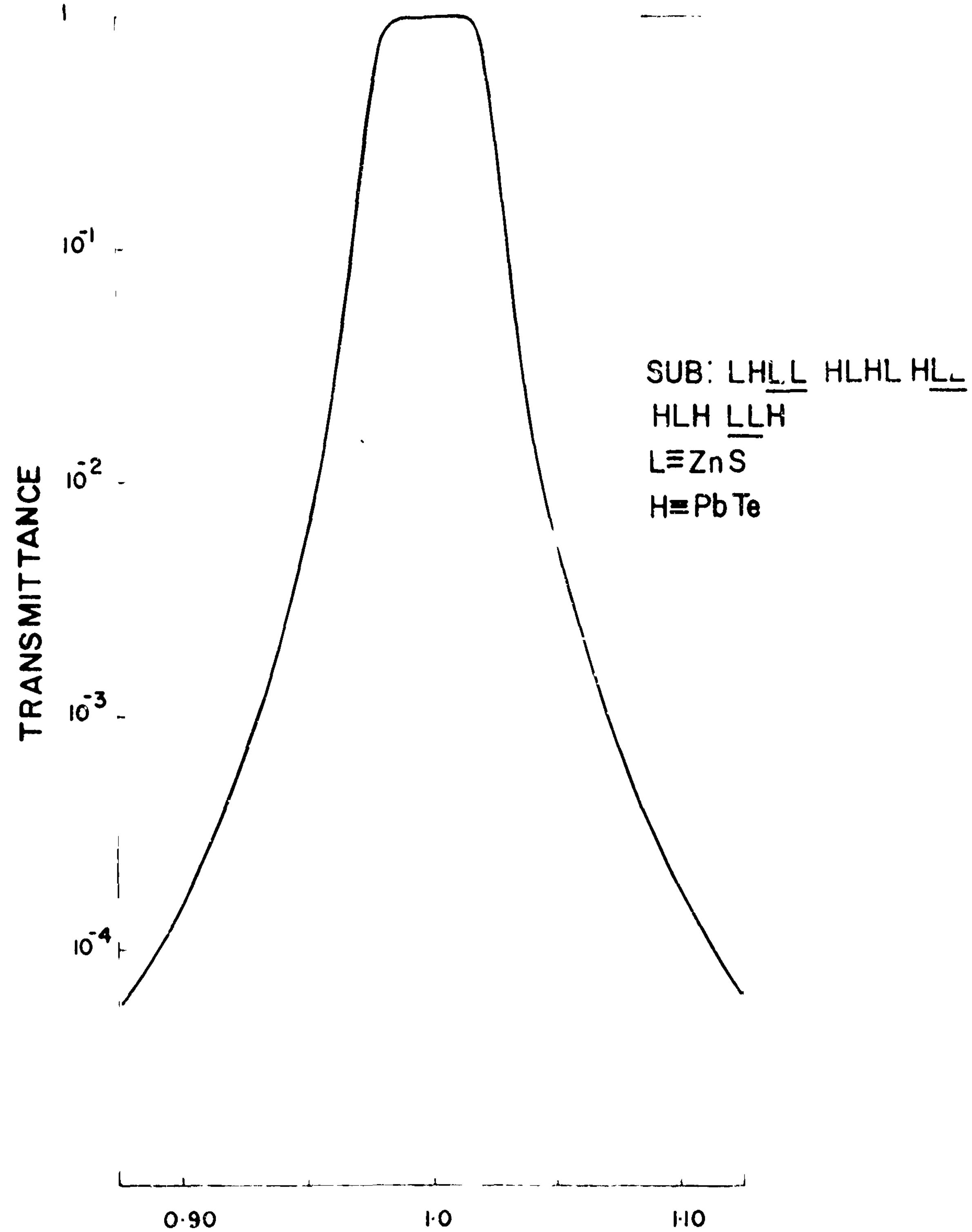


FIG. 5·6 COMPUTED TCHEBYSHEV NARROWBAND FILTER (16 LAYER, TRIPLE HALFWAVE DESIGN)

Fig: 5.7 SPECTRAL SENSITIVITY (REFLECTIVITY) OF LAYERS IN 10-LAYER RADIOMETER F.P. FILTER

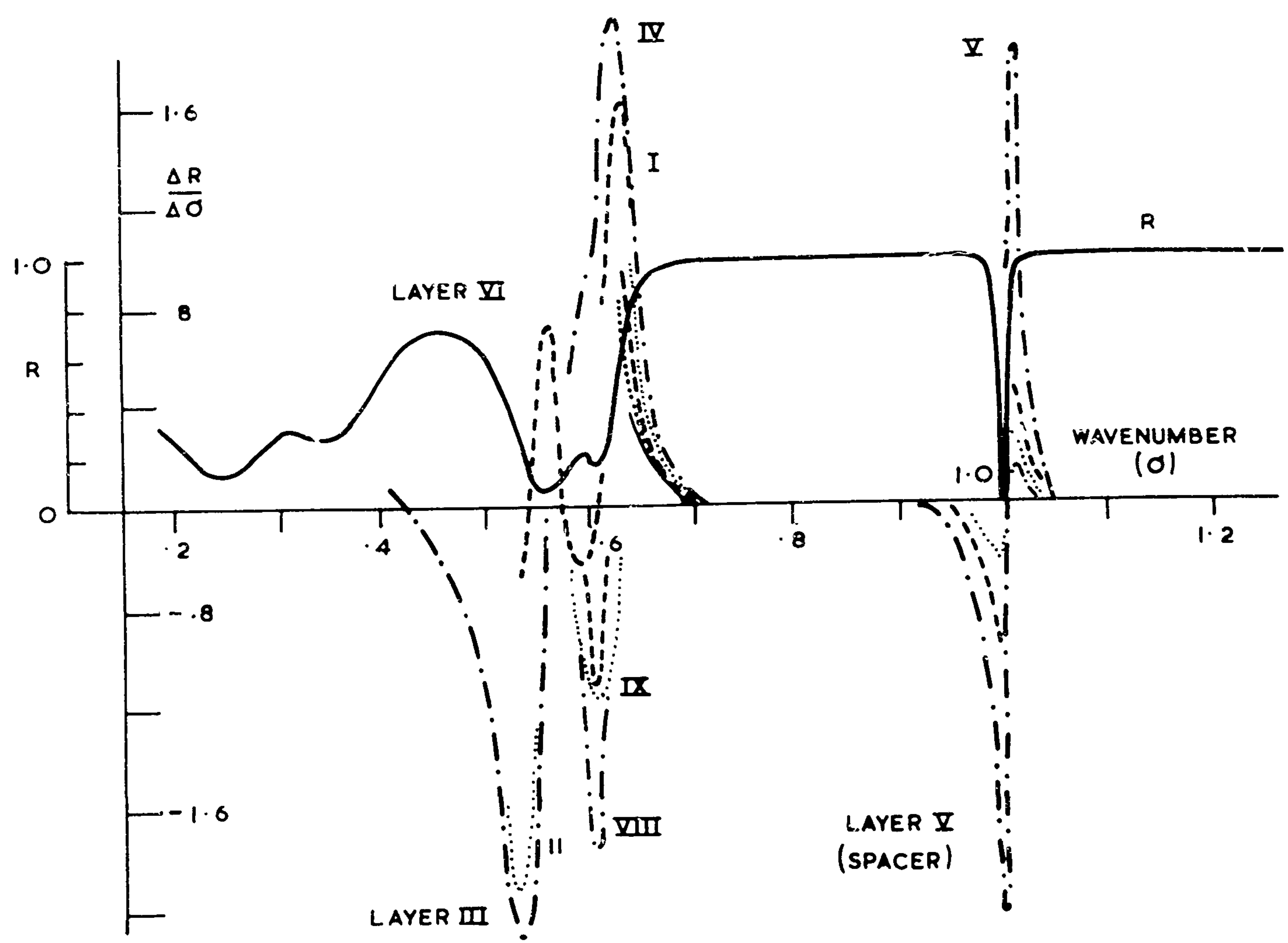
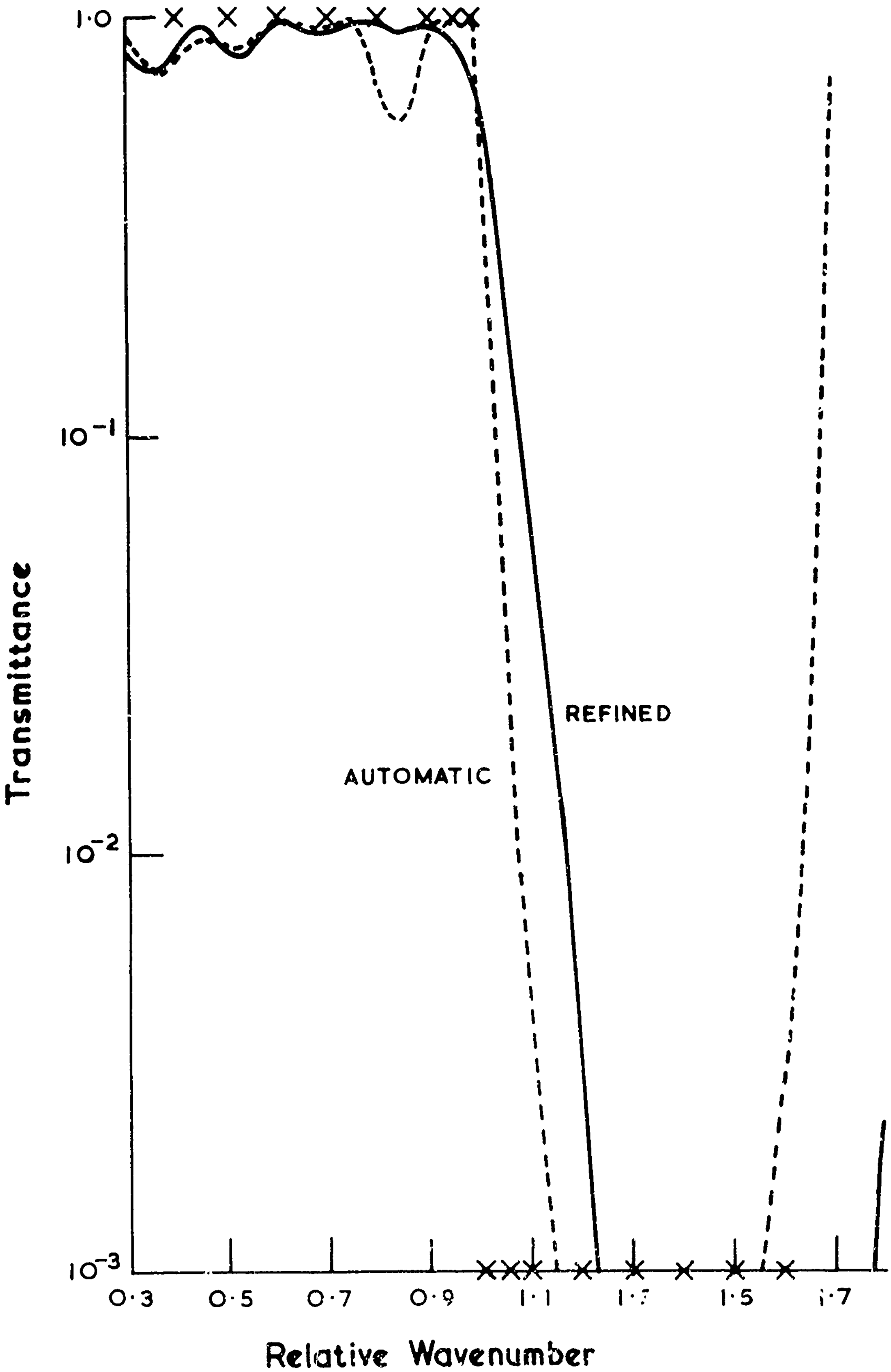


Fig: 5. 8 REFINEMENT OF LOW PASS DESIGN IN FIG: 5.5 AND TABLE 5.1



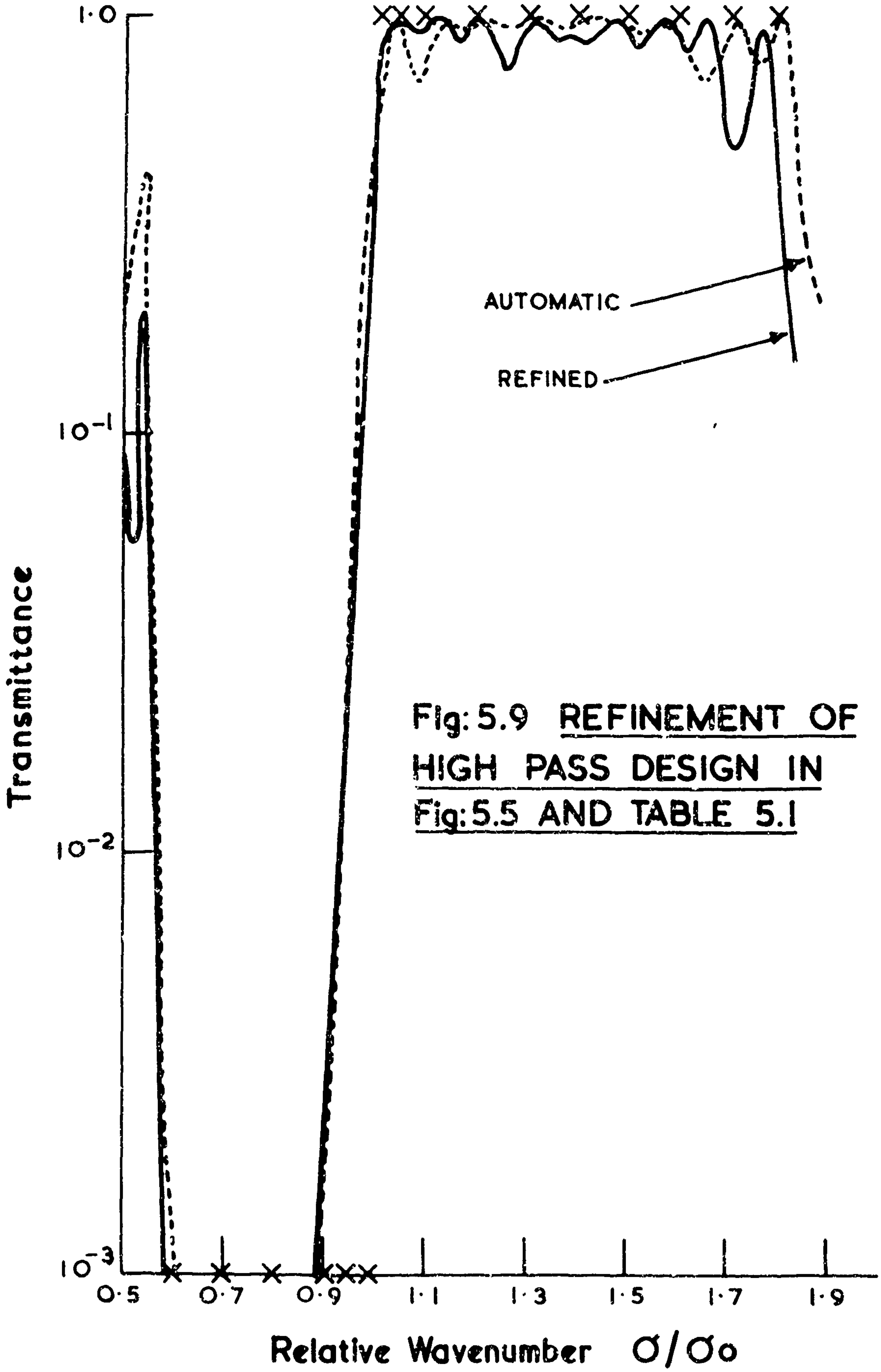


Fig: 5.9 REFINEMENT OF HIGH PASS DESIGN IN Fig: 5.5 AND TABLE 5.1

10-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS
2.3500	0.2567
5.3000	0.2458
2.3500	0.2545
5.3000	0.2530
2.3500	0.2611
5.3000	0.5080
2.3500	0.2515
5.3000	0.2537
2.3500	0.2406
5.3000	0.2522

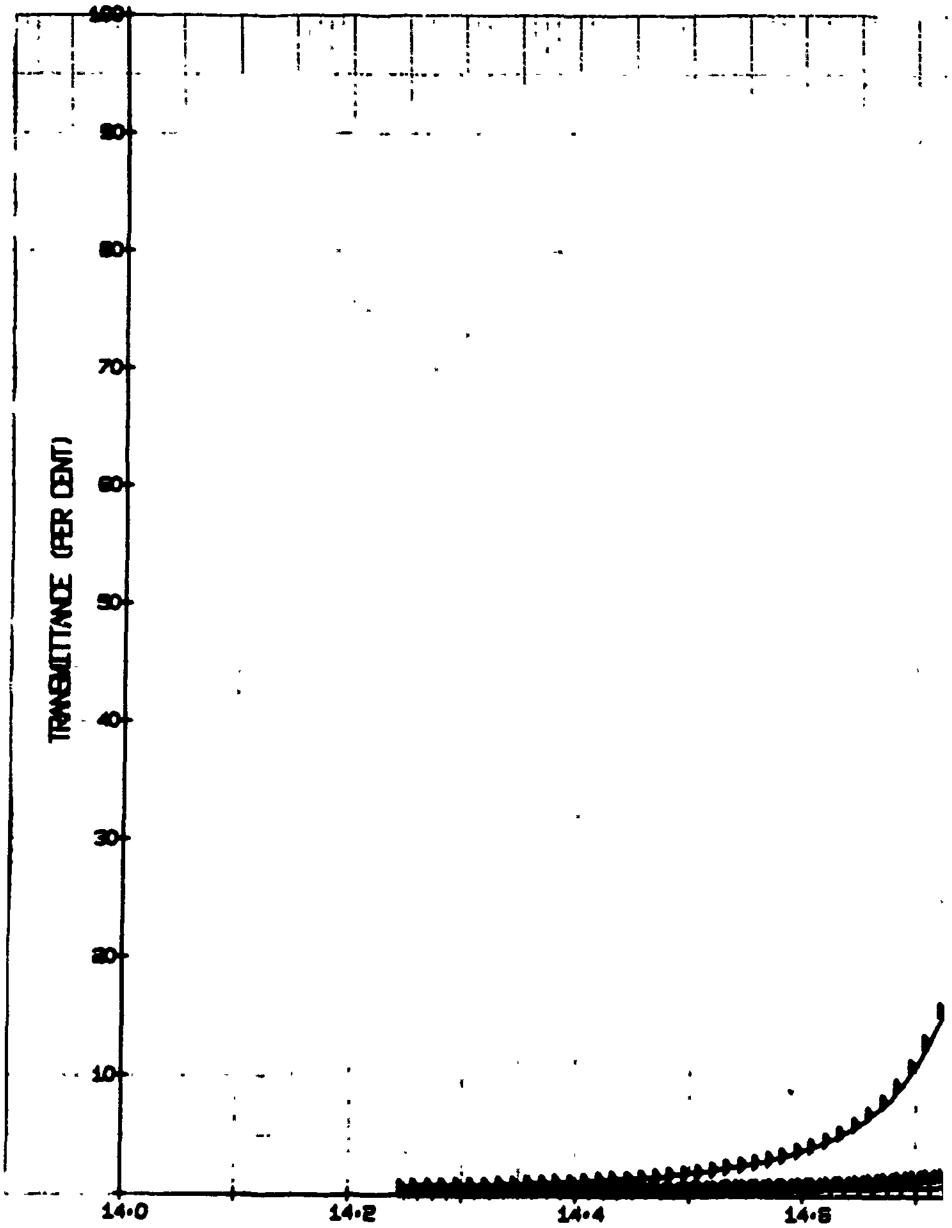
CASE NO. 2

LAYER INDEX	LAYER THICKNESS
2.3500	0.2534
5.3000	0.2444
2.3500	0.2550
5.3000	0.2454
2.3500	0.2554
5.3000	0.5003
2.3500	0.2495
5.3000	0.2586
2.3500	0.2524
5.3000	0.2558

CASE NO. 3

LAYER INDEX	LAYER THICKNESS
2.3500	0.2590
5.3000	0.2468
2.3500	0.2493
5.3000	0.2465
2.3500	0.2534
5.3000	0.4900
2.3500	0.2463
5.3000	0.2522
2.3500	0.2529
5.3000	0.2532

END OF CALCULATIONS



A

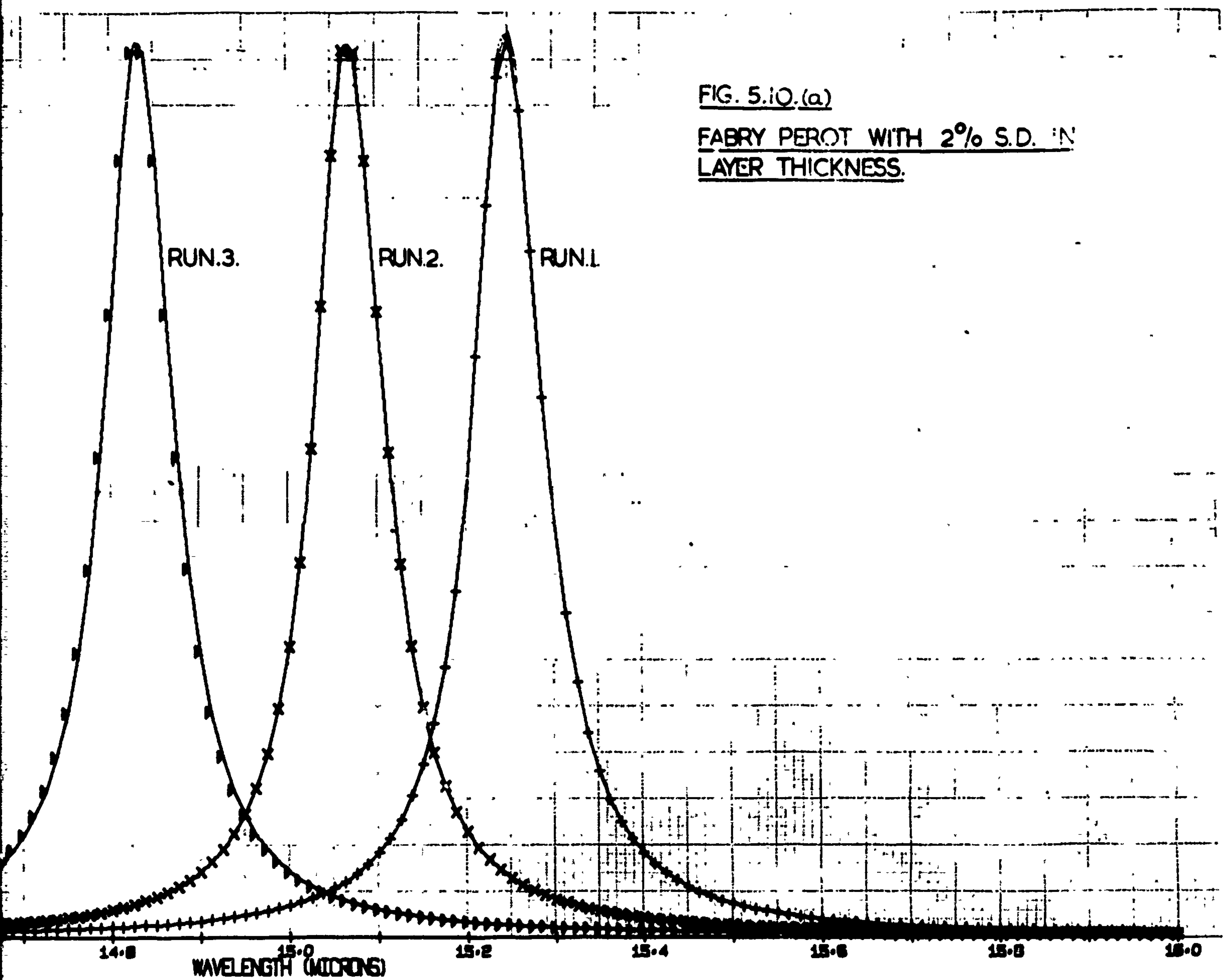


FIG. 5.10.(a)

FABRY PEROT WITH 2% S.D. IN LAYER THICKNESS.

B

10-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS
2.3500	0.2493
5.3000	0.2421
2.3500	0.2552
5.3000	0.2487
2.3500	0.2474
5.3000	0.4929
2.3500	0.2558
5.3000	0.2555
2.3500	0.2454
5.3000	0.2507

4

CASE NO. 2

LAYER INDEX	LAYER THICKNESS
2.3500	0.2513
5.3000	0.2573
2.3500	0.2385
5.3000	0.2450
2.3500	0.2519
5.3000	0.5082
2.3500	0.2515
5.3000	0.2493
2.3500	0.2424
5.3000	0.2559

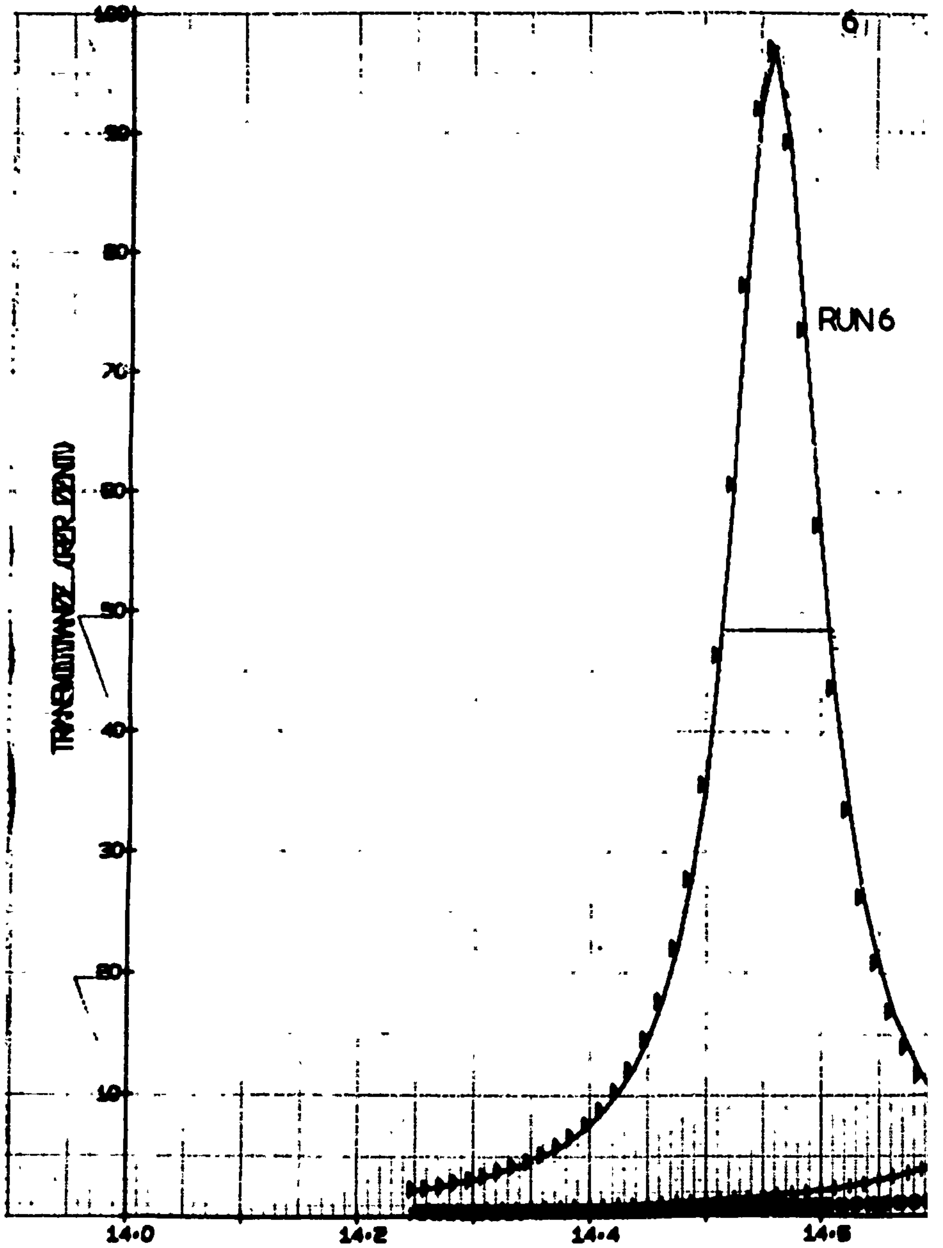
5

CASE NO. 3

LAYER INDEX	LAYER THICKNESS
2.3500	0.2496
5.3000	0.2436
2.3500	0.2580
5.3000	0.2526
2.3500	0.2526
5.3000	0.4759
2.3500	0.2435
5.3000	0.2444
2.3500	0.2457
5.3000	0.2572

6

END OF CALCULATIONS



A

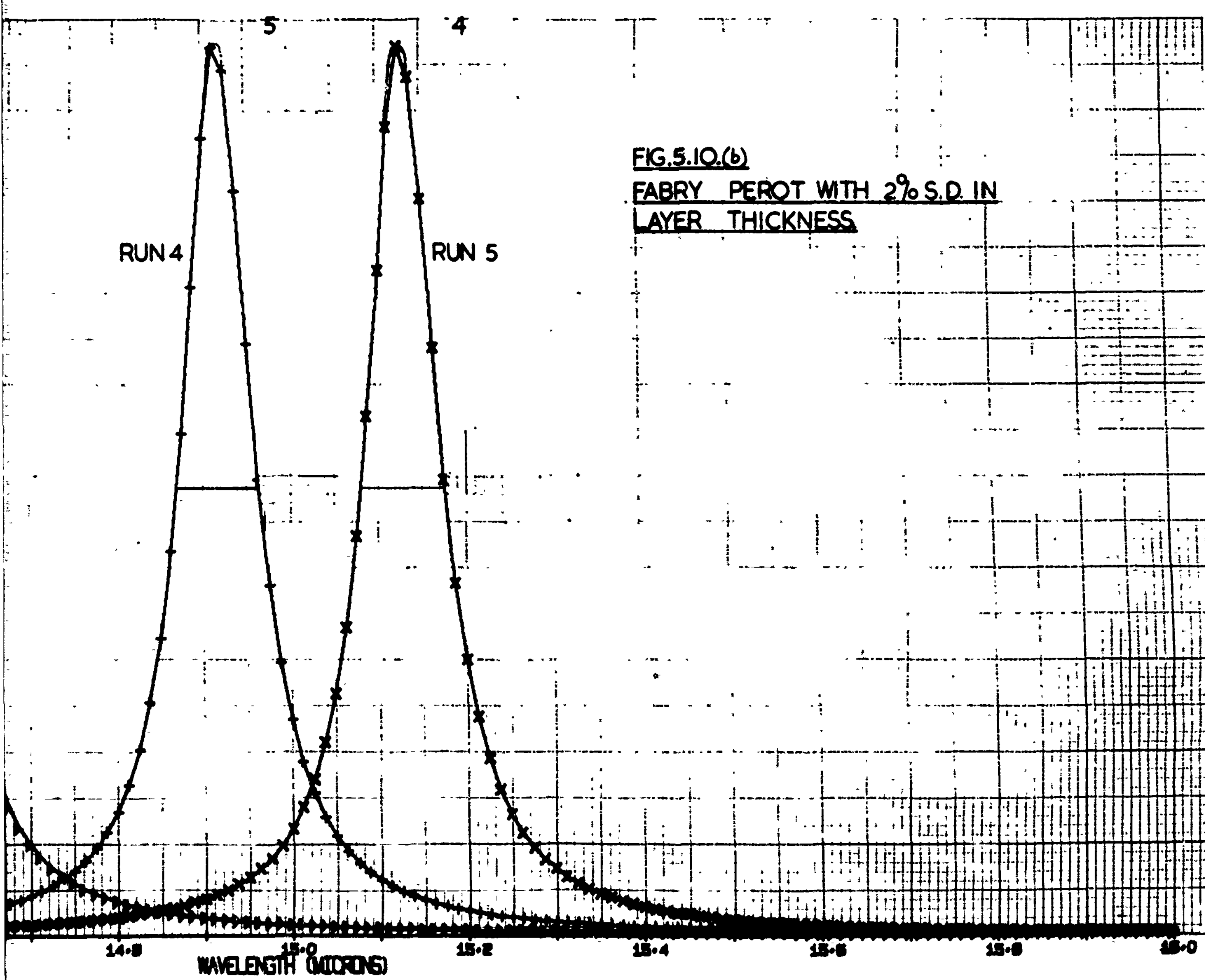
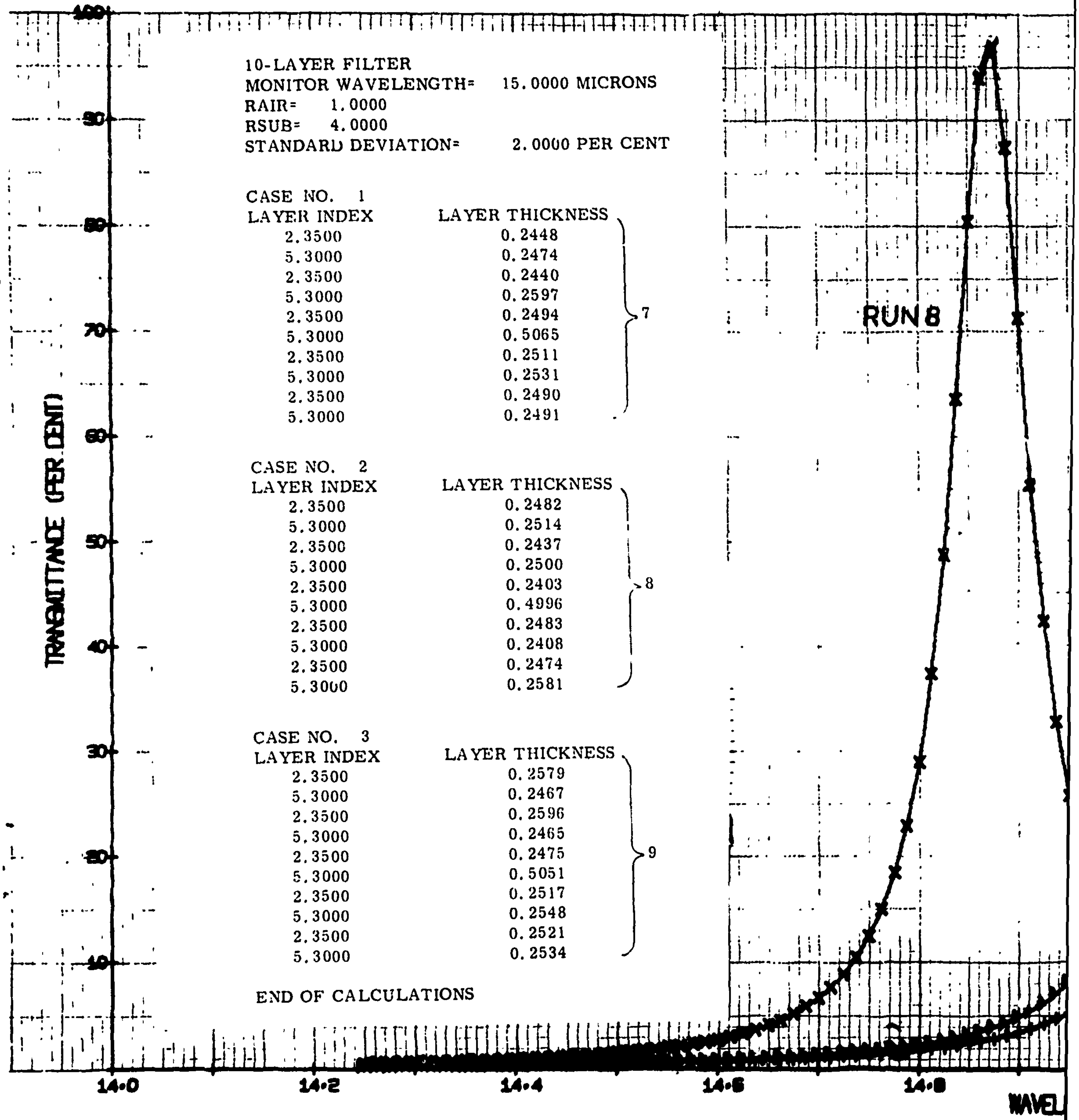


FIG.5.10.(b)
FABRY PEROT WITH 2% S.D. IN LAYER THICKNESS

B



10-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS
2.3500	0.2448
5.3000	0.2474
2.3500	0.2440
5.3000	0.2597
2.3500	0.2494
5.3000	0.5065
2.3500	0.2511
5.3000	0.2531
2.3500	0.2490
5.3000	0.2491

7

CASE NO. 2

LAYER INDEX	LAYER THICKNESS
2.3500	0.2482
5.3000	0.2514
2.3500	0.2437
5.3000	0.2500
2.3500	0.2403
5.3000	0.4996
2.3500	0.2483
5.3000	0.2408
2.3500	0.2474
5.3000	0.2581

8

CASE NO. 3

LAYER INDEX	LAYER THICKNESS
2.3500	0.2579
5.3000	0.2467
2.3500	0.2596
5.3000	0.2465
2.3500	0.2475
5.3000	0.5051
2.3500	0.2517
5.3000	0.2548
2.3500	0.2521
5.3000	0.2534

9

END OF CALCULATIONS

A

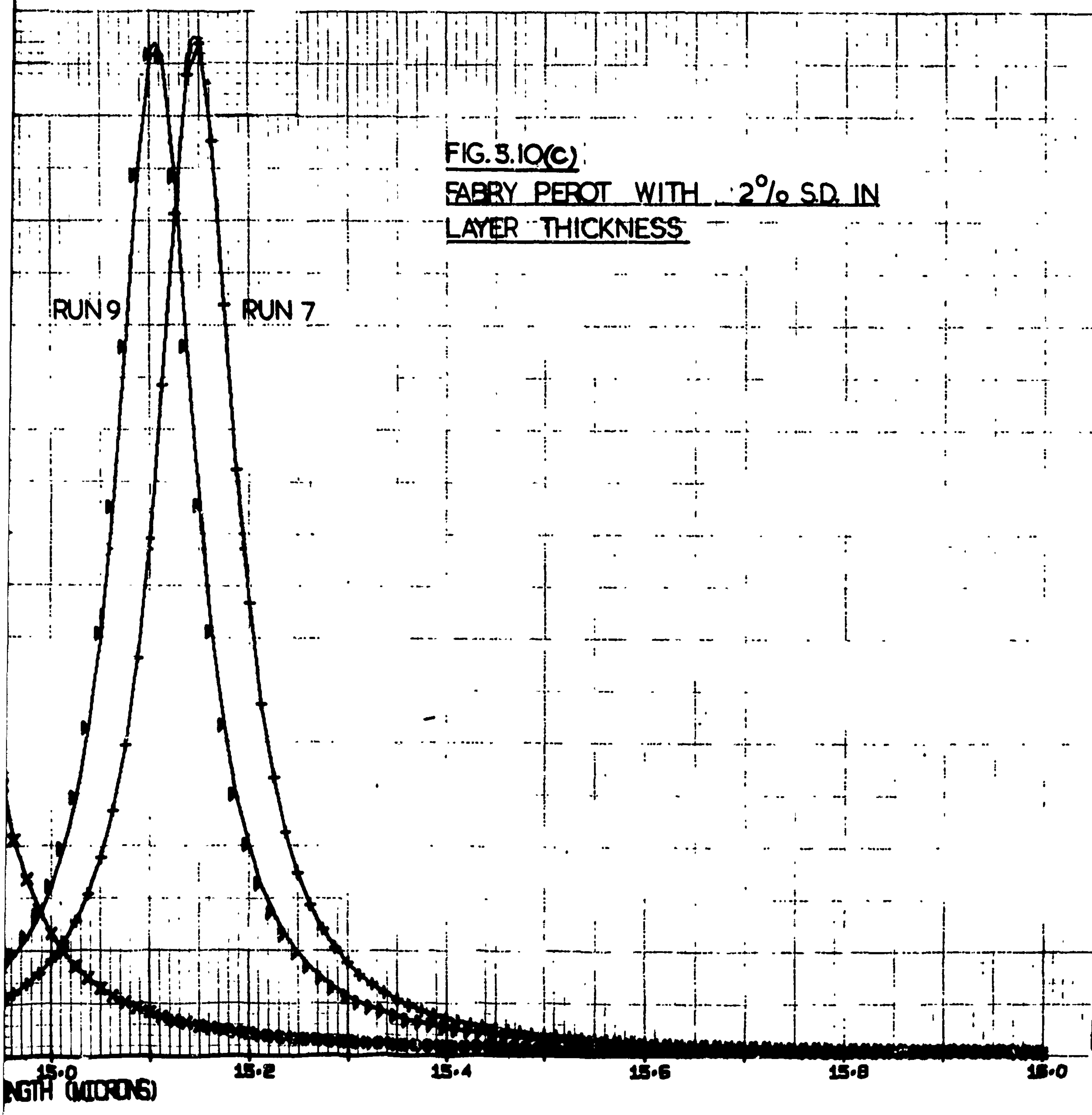


FIG. 3.10(C)
FABRY PEROT WITH 2% S.D. IN LAYER THICKNESS
RUN 9
RUN 7
15·0
15·2
15·4
15·6
15·8
16·0
NGTH (MICRONS)

B

10-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2436	
5.3000	0.2518	
2.3500	0.2496	
5.3000	0.2521	
2.3500	0.2493	
5.3000	0.5125	1
2.3500	0.2528	
5.3000	0.2441	
2.3500	0.2500	
5.3000	0.2507	

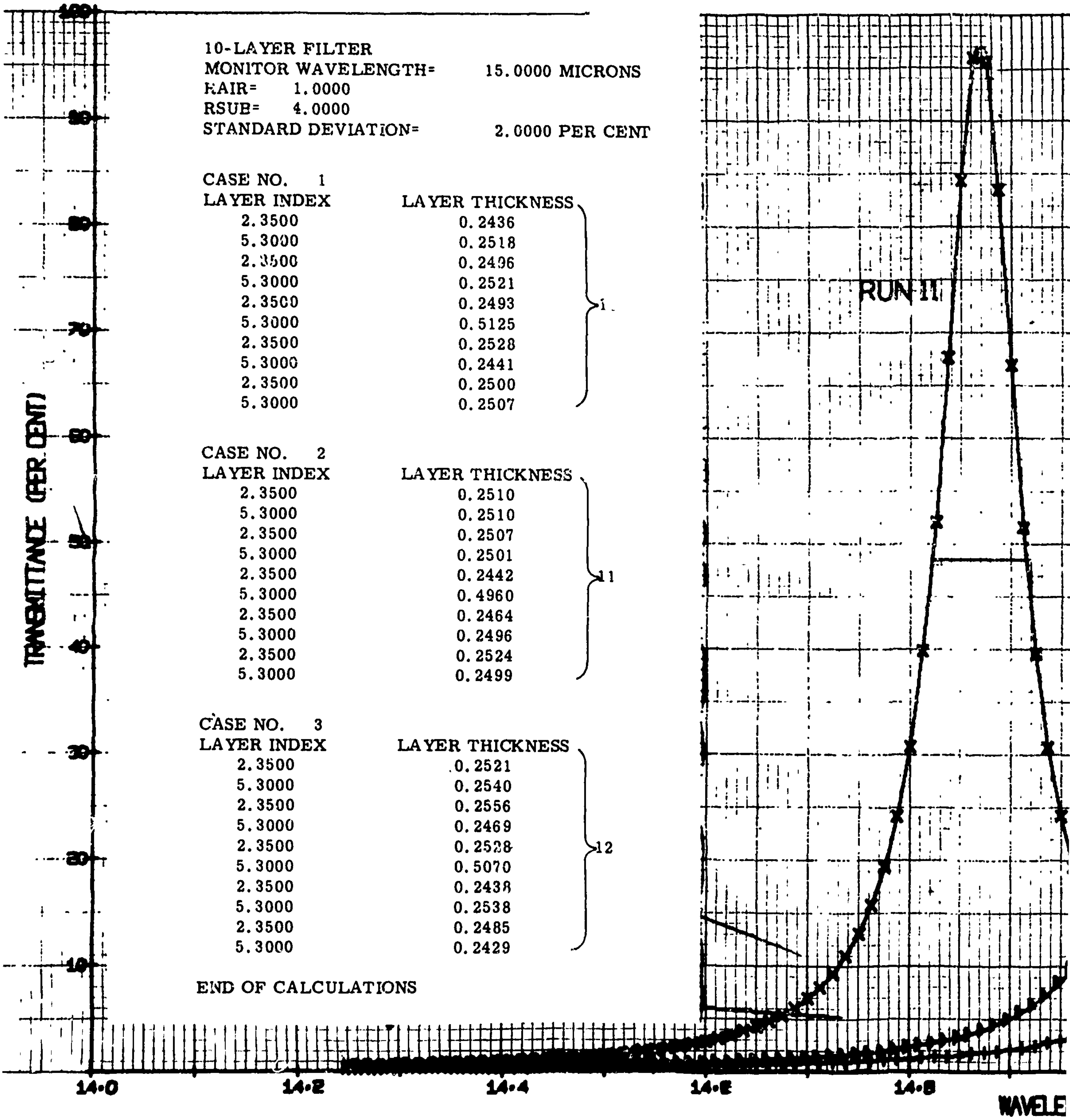
CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2510	
5.3000	0.2510	
2.3500	0.2507	
5.3000	0.2501	
2.3500	0.2442	11
5.3000	0.4960	
2.3500	0.2464	
5.3000	0.2496	
2.3500	0.2524	
5.3000	0.2499	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2521	
5.3000	0.2540	
2.3500	0.2556	
5.3000	0.2469	
2.3500	0.2528	12
5.3000	0.5070	
2.3500	0.2438	
5.3000	0.2538	
2.3500	0.2485	
5.3000	0.2429	

END OF CALCULATIONS



A

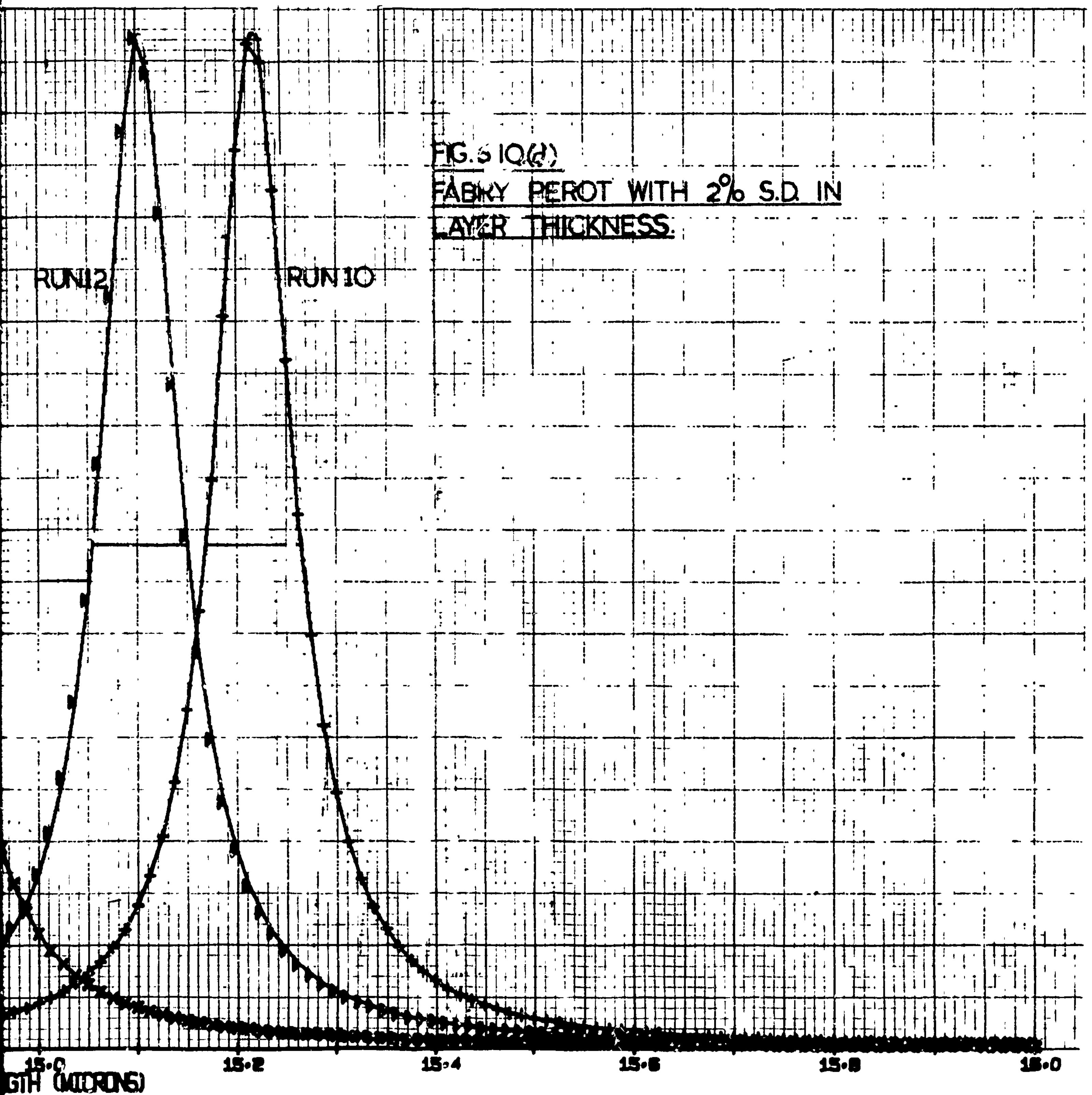


FIG.5 IO(d)
FABRY PEROT WITH 2% S.D. IN
LAYER THICKNESS.
RUN12
RUN 10
15·0
15·2
15·4
15·6
15·8
16·0
GTH (MICRONS)

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2436	
5.3000	0.2518	
2.3500	0.2496	
5.3000	0.5043	
2.3500	0.2493	
5.3000	0.2562	
2.3500	0.2528	1
5.3000	0.2441	
2.3500	0.2500	
5.3000	0.2507	
2.3500	0.2510	
5.3000	0.5021	
2.3500	0.2507	
5.3000	0.2501	

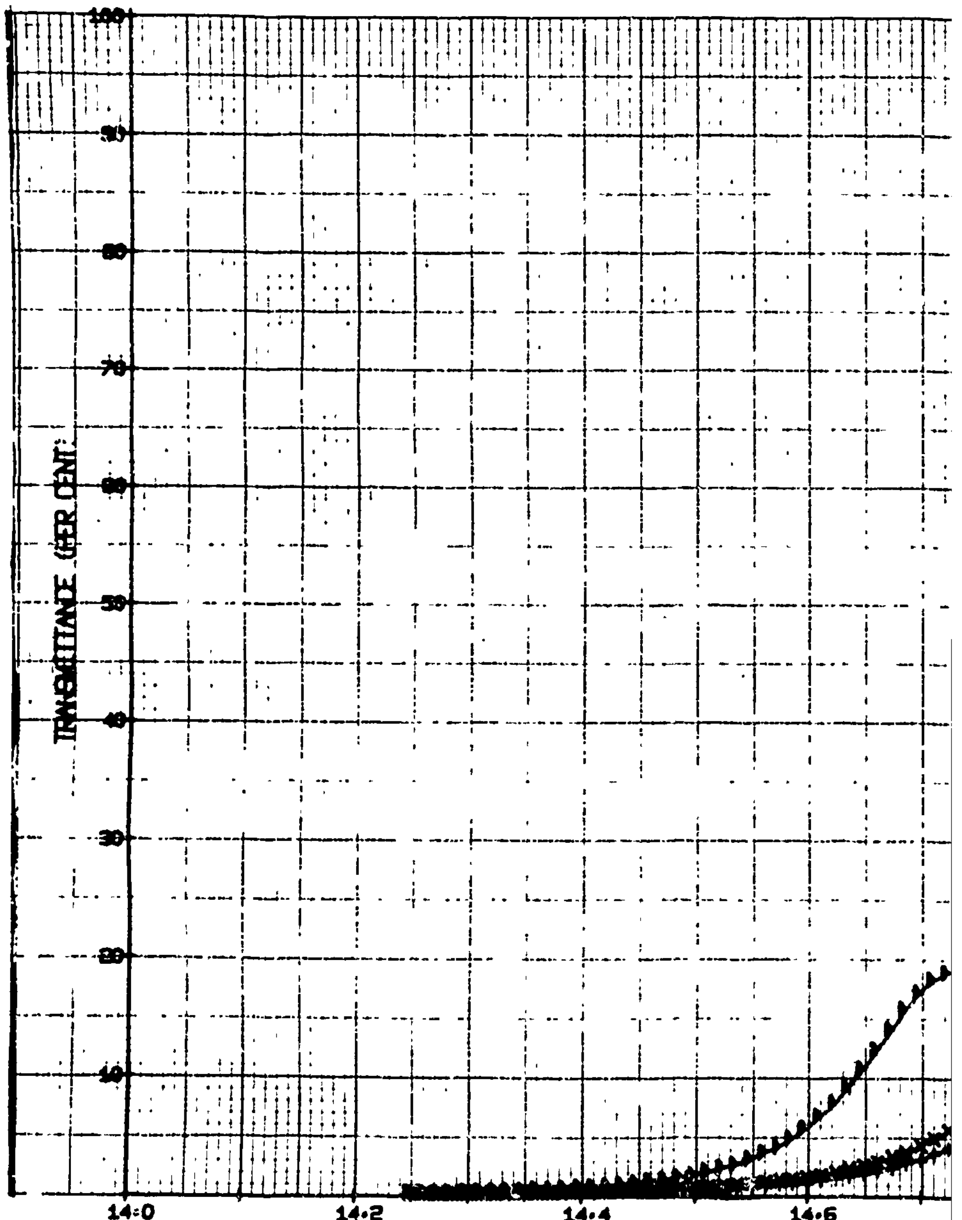
CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2442	
5.3000	0.2480	
2.3500	0.2464	
5.3000	0.4992	
2.3500	0.2524	
5.3000	0.2449	
2.3500	0.2521	2
5.3000	0.2540	
2.3500	0.2556	
5.3000	0.2469	
2.3500	0.2528	
5.3000	0.5070	
2.3500	0.2438	
5.3000	0.2538	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2485	
5.3000	0.2429	
2.3500	0.2620	
5.3000	0.5116	
2.3500	0.2442	
5.3000	0.2574	
2.3500	0.2502	3
5.3000	0.2477	
2.3500	0.2449	
5.3000	0.2518	
2.3500	0.2434	
5.3000	0.4894	
2.3500	0.2457	
5.3000	0.2513	

END OF CALCULATIONS



A

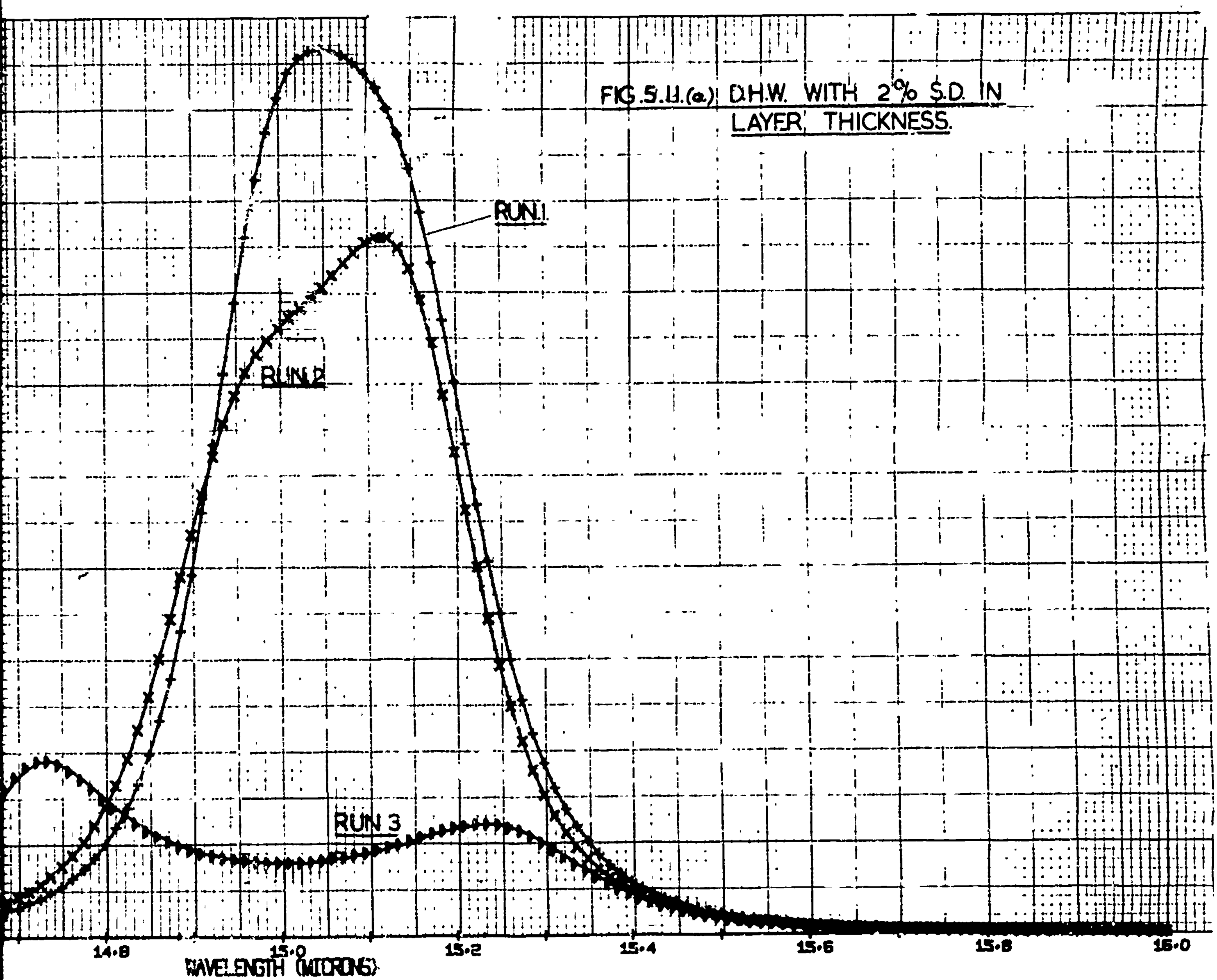


FIG.5.11.(a) D.H.W. WITH 2% S.D. IN LAYER THICKNESS.
RUN.1
RUN.2
RUN 3
14.8
15.0
15.2
15.4
15.6
15.8
16.0
WAVELENGTH (MICRONS)

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS
2.3500	0.2448
5.3000	0.2474
2.3500	0.2440
5.3000	0.5194
2.3500	0.2493
5.3000	0.2532
2.3500	0.2511
5.3000	0.2531
2.3500	0.2490
5.3000	0.2491
2.3500	0.2482
5.3000	0.5029
2.3500	0.2437
5.3000	0.2500

4

CASE NO. 2

LAYER INDEX	LAYER THICKNESS
2.3500	0.2403
5.3000	0.2498
2.3500	0.2483
5.3000	0.4817
2.3500	0.2474
5.3000	0.2581
2.3500	0.2579
5.3000	0.2467
2.3500	0.2596
5.3000	0.2465
2.3500	0.2475
5.3000	0.5051
2.3500	0.2517
5.3000	0.2548

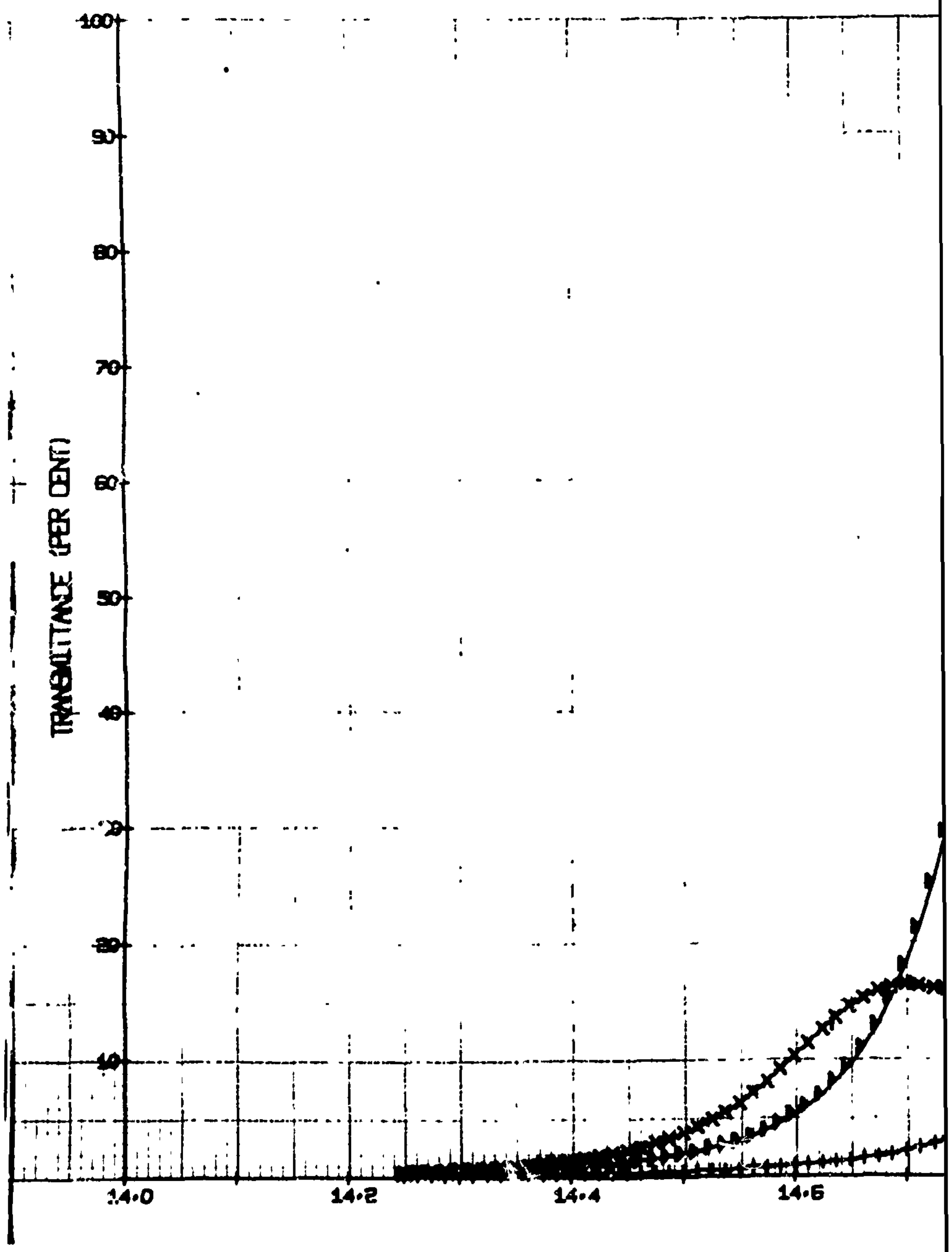
5

CASE NO. 3

LAYER INDEX	LAYER THICKNESS
2.3500	0.2521
5.3000	0.2534
2.3500	0.2438
5.3000	0.4965
2.3500	0.2467
5.3000	0.2493
2.3500	0.2559
5.3000	0.2466
2.3500	0.2513
5.3000	0.2501
2.3500	0.2480
5.3000	0.4999
2.3500	0.2459
5.3000	0.2510

6

END OF CALCULATIONS



A

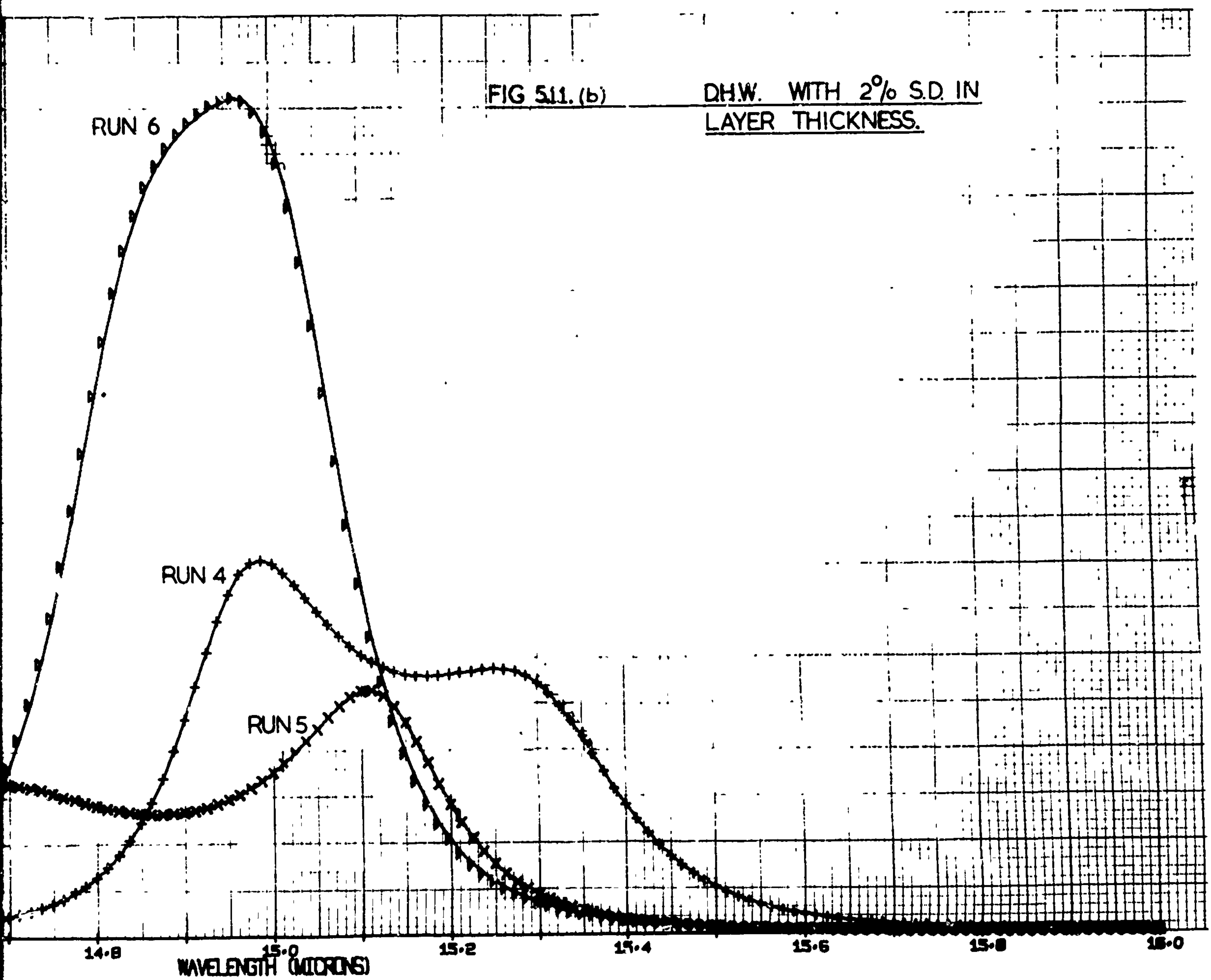


FIG 5.11. (b)
D.H.W. WITH 2% S.D IN LAYER THICKNESS.
RUN 6
RUN 4
RUN 5
14·8
15·0
15·2
15·4
15·6
15·8
16·0
WAVELENGTH (MICRONS)

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2493	
5.3000	0.2421	
2.3500	0.2552	
5.3000	0.4974	
2.3500	0.2474	
5.3000	0.2464	
2.3500	0.2558	7
5.3000	0.2555	
2.3500	0.2454	
5.3000	0.2507	
2.3500	0.2513	
5.3000	0.5146	
2.3500	0.2385	
5.3000	0.2450	

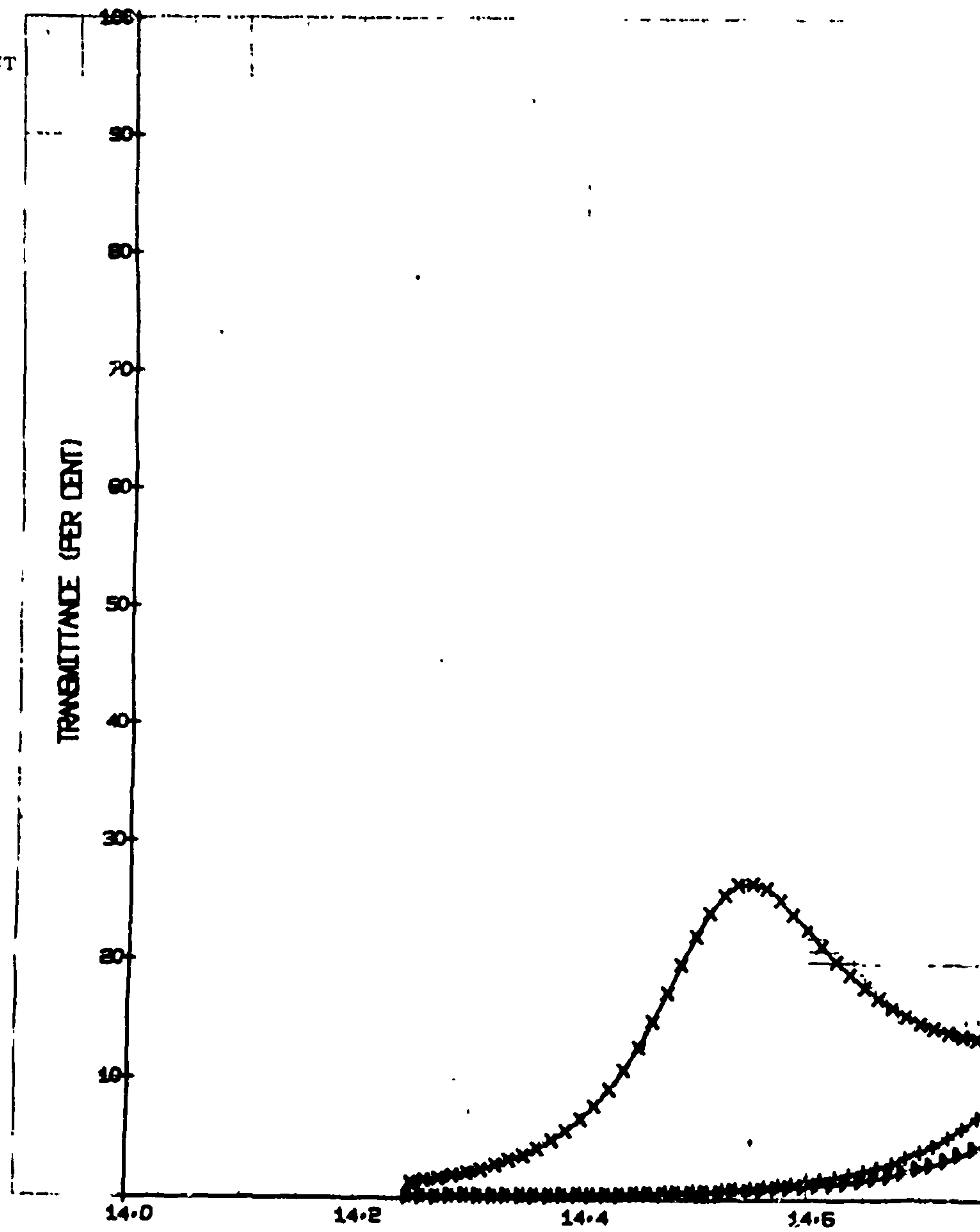
CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2519	
5.3000	0.2541	
2.3500	0.2515	
5.3000	0.4987	
2.3500	0.2424	
5.3000	0.2559	
2.3500	0.2496	8
5.3000	0.2436	
2.3500	0.2580	
5.3000	0.2526	
2.3500	0.2526	
5.3000	0.4759	
2.3560	0.2435	
5.3000	0.2444	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2457	
5.3000	0.2572	
2.3500	0.2541	
5.3000	0.5025	
2.3500	0.2537	
5.3000	0.2515	
2.3500	0.2546	9
5.3000	0.2430	
2.3500	0.2468	
5.3000	0.2458	
2.3500	0.2402	
5.3000	0.5097	
2.3500	0.2498	
5.3000	0.2451	

END OF CALCULATIONS



A

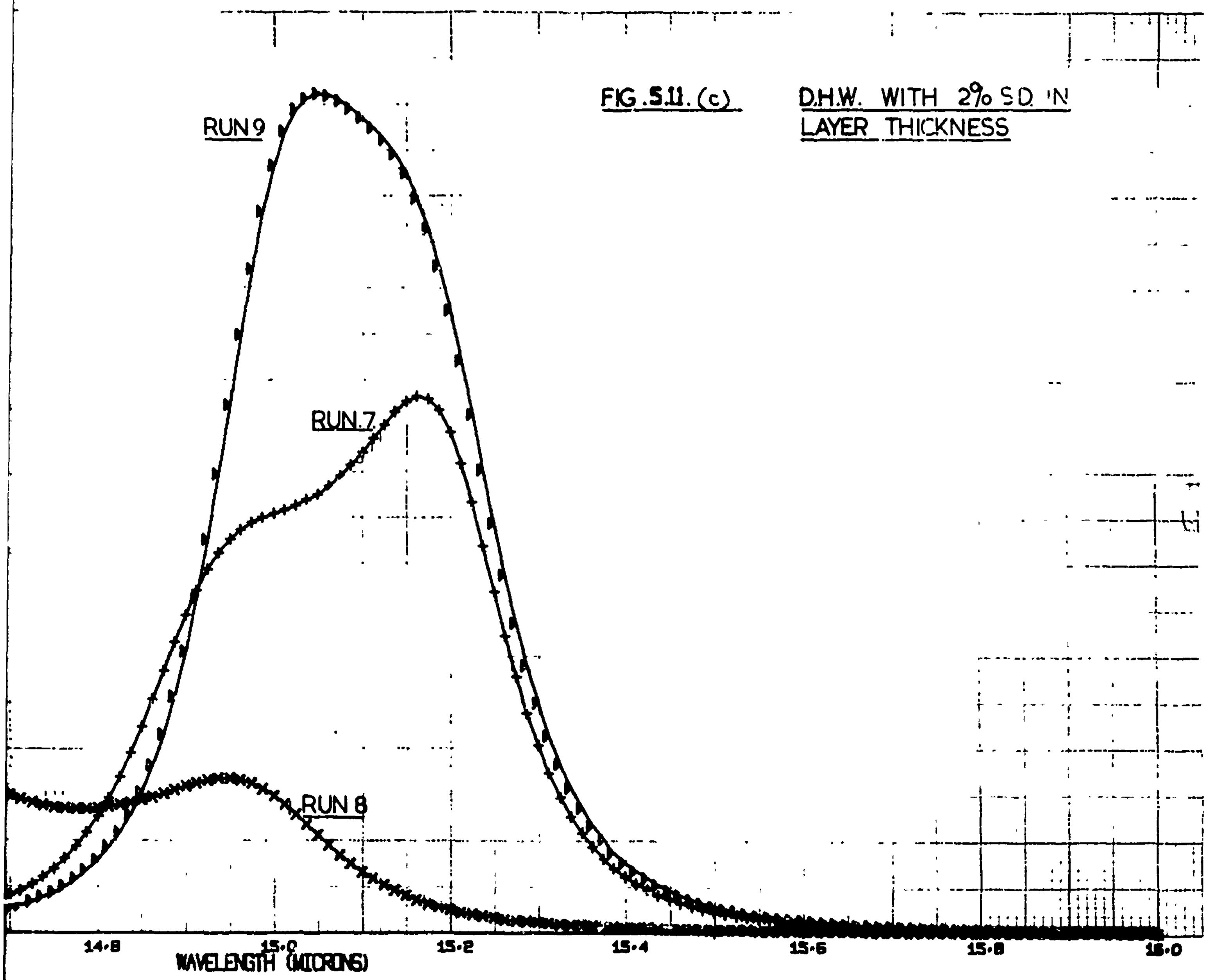


FIG. 5.11. (c)
D.H.W. WITH 2% S.D. IN LAYER THICKNESS
RUN 9
RUN 7
RUN 8
14·8
15·0
15·2
15·4
15·6
15·8
16·0
WAVELENGTH (MICRONS)

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION- 2.0000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2567	
5.3000	0.2458	
2.3500	0.2545	
5.3000	0.5060	
2.3500	0.2611	
5.3000	0.2540	
2.3500	0.2515	10
5.3000	0.2537	
2.3500	0.2406	
5.3000	0.2522	
2.3500	0.2534	
5.3000	0.4889	
2.3500	0.2550	
5.3000	0.2454	

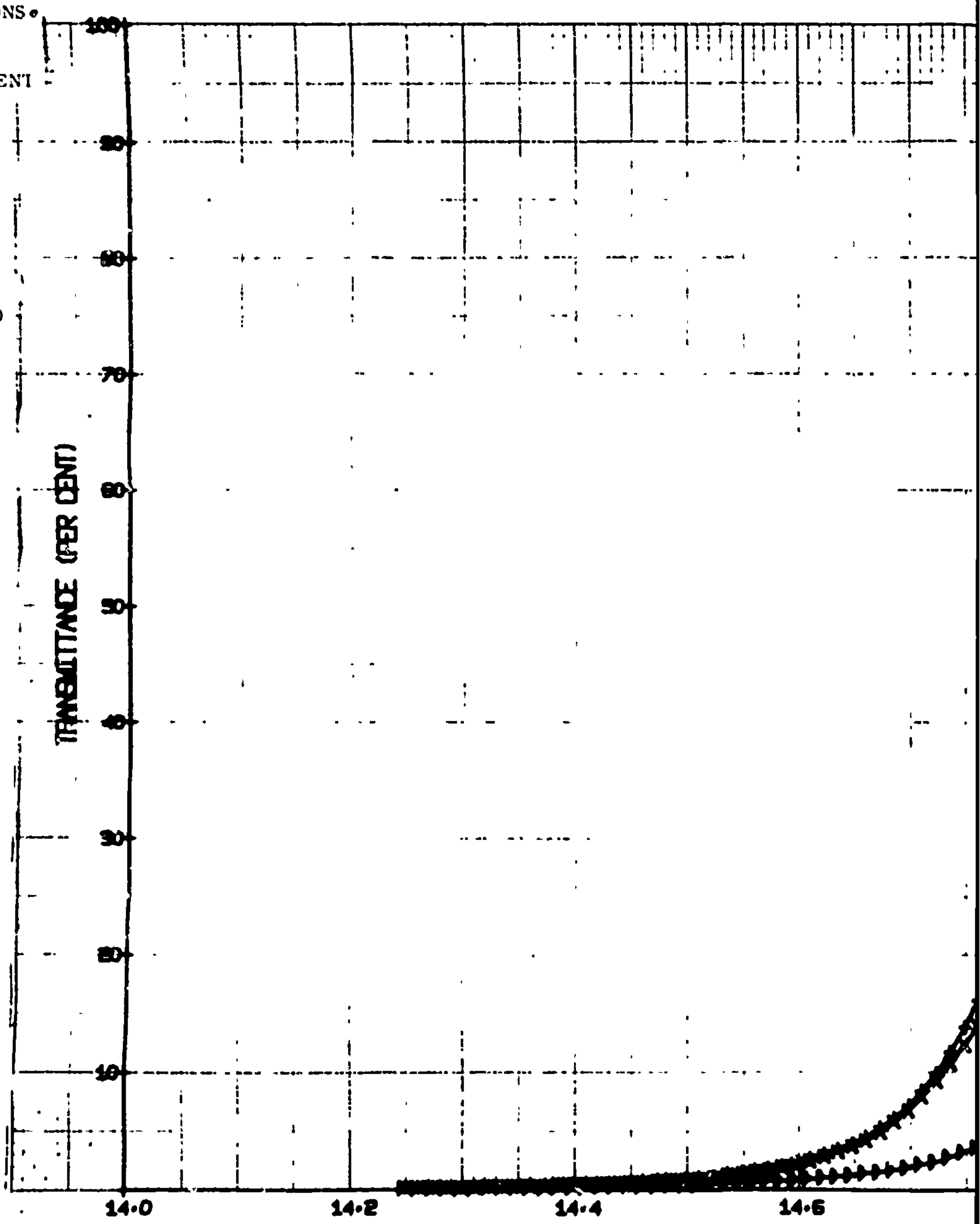
CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2554	
5.3000	0.2501	
2.3500	0.2495	
5.3000	0.5172	
2.3500	0.2524	
5.3000	0.2558	
2.3500	0.2590	11
5.3000	0.2468	
2.3500	0.2493	
5.3000	0.2465	
2.3500	0.2534	
5.3000	0.4900	
2.3500	0.2463	
5.3000	0.2522	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2529	
5.3000	0.2532	
2.3500	0.2532	
5.3000	0.5159	
2.3500	0.2473	
5.3000	0.2464	
2.3500	0.2552	12
5.3000	0.2536	
2 3500	0.2518	
5.3000	0.2446	
2.3500	0.2521	
5.3000	0.4987	
2.3500	0.2512	
5.3000	0.2528	

END OF CALCULATIONS



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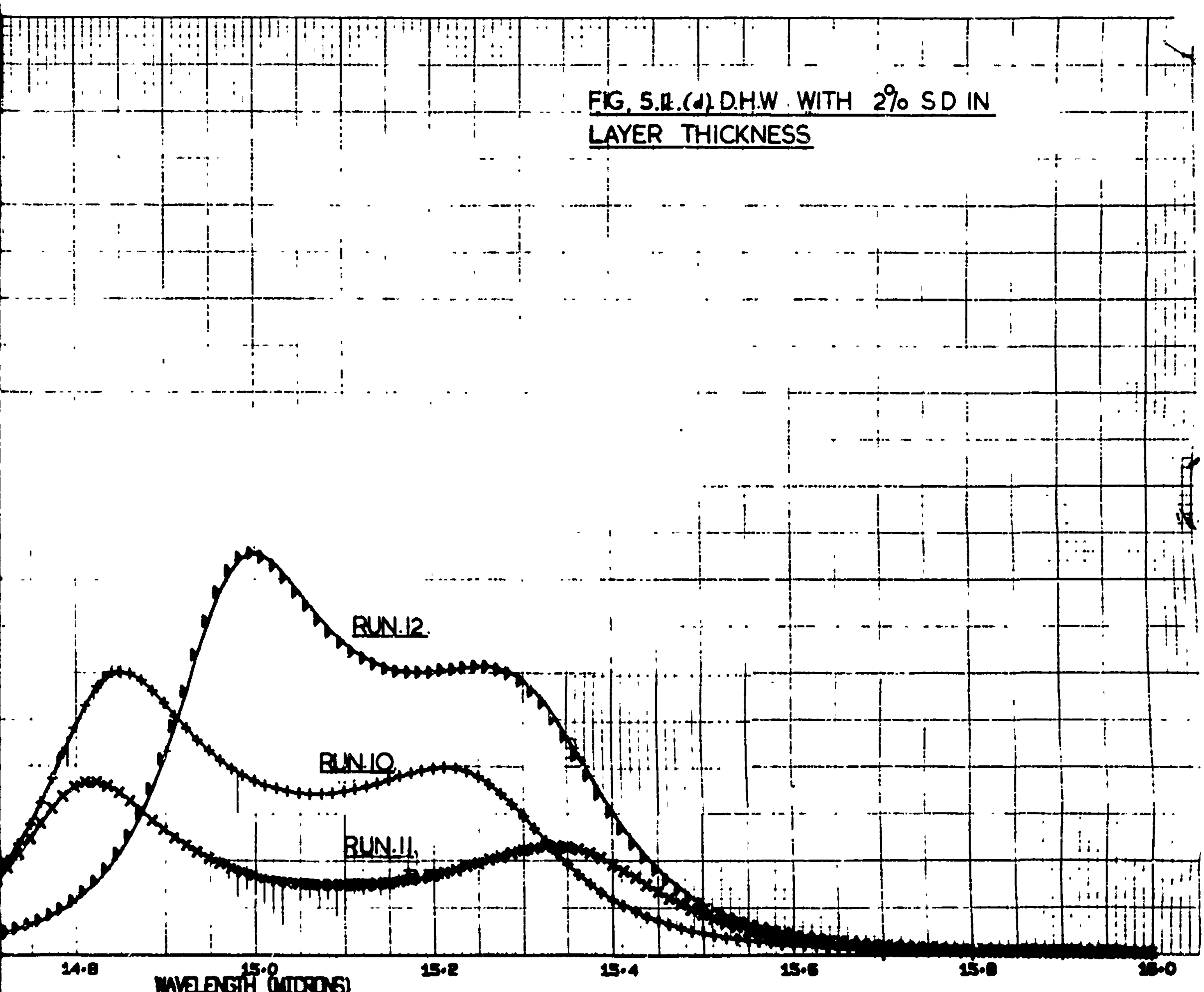


FIG. 5.11.(d) D.H.W WITH 2% SD IN LAYER THICKNESS

B

PEAK TRANSMISSION AS A FUNCTION OF HALF-WIDTH FOR THE D.H.W Ge/ LHL HH LH LH LHL HH LH FOR 2% & 1·4% S.D. IN LAYER THICKNESS.

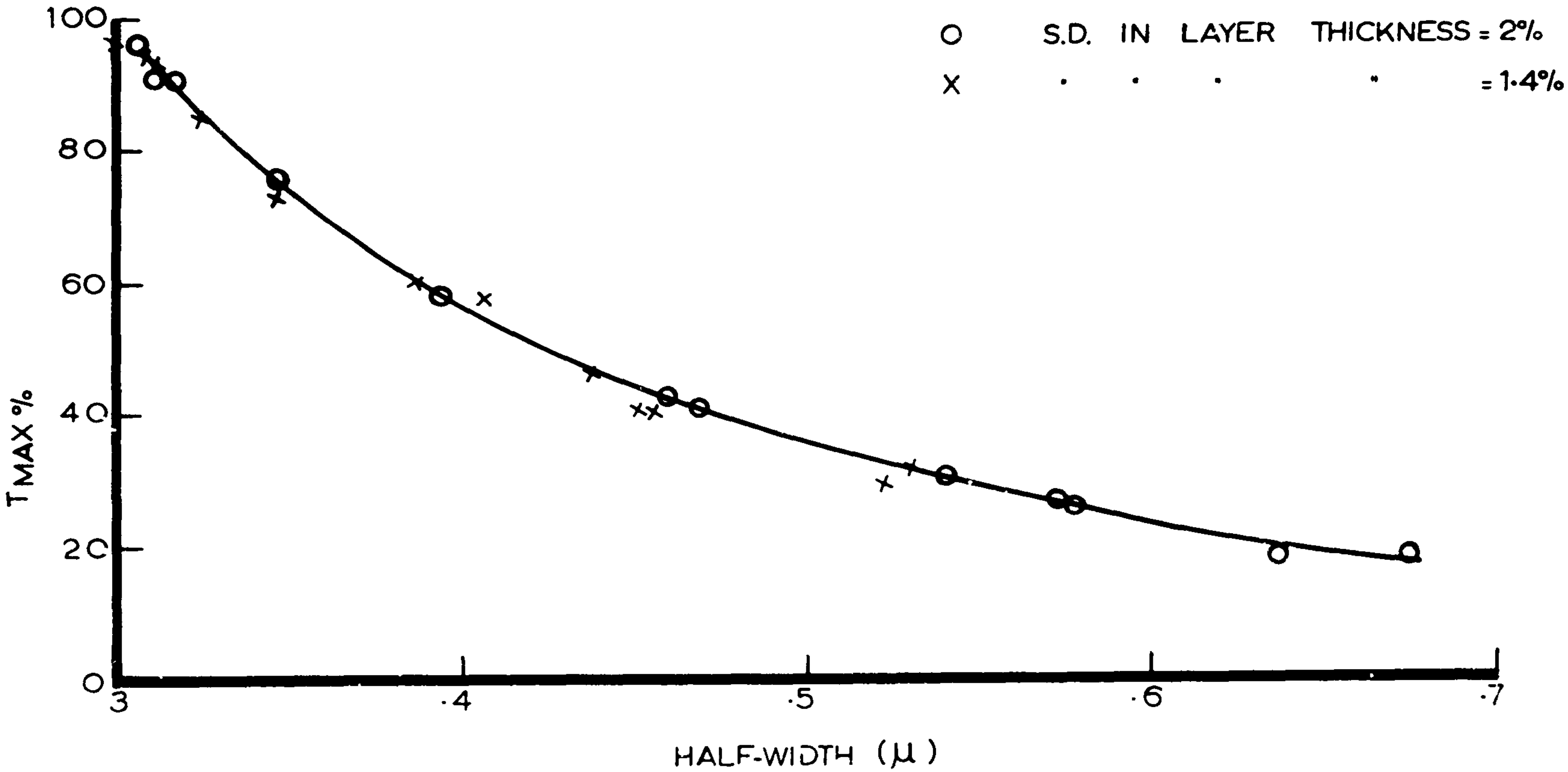


FIG. 5.12.

PEAK TRANSMISSION AND HALFWIDTH OF THE D.H.W. DESIGN Ge/LHL HH LHLHLHL HH LH AS A FUNCTION OF $/\lambda_p - \lambda_c/$ FOR 2% AND 1.4% SD IN LAYER THICKNESS.

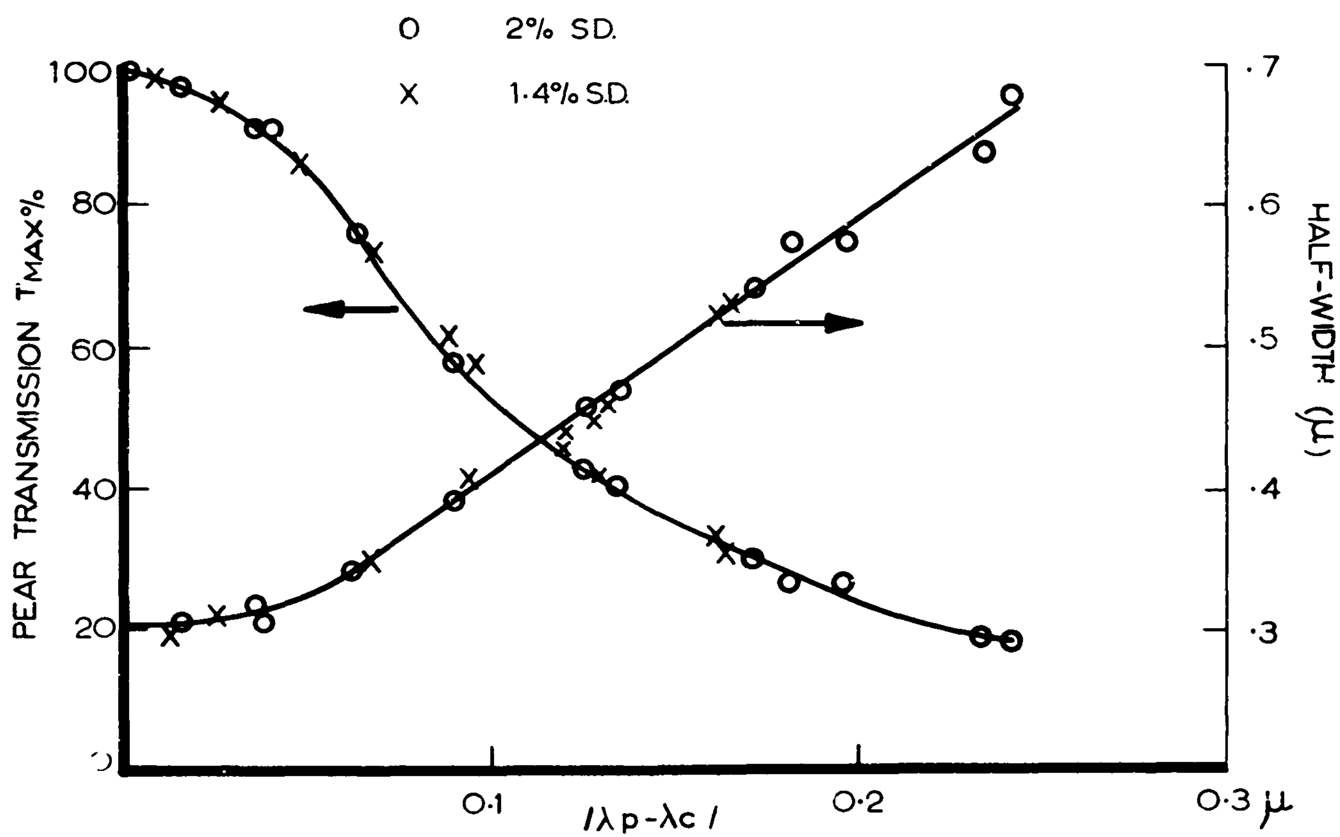


FIG.5.13.

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 1.4000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS
2.3500	0.2455
5.3000	0.2512
2.3500	0.2497
5.3000	0.5030
2.3500	0.2495
5.3000	0.2543
2.3500	0.2519
5.3000	0.2458
2.3500	0.2500
5.3000	0.2505
2.3500	0.2507
5.3000	0.5015
2.3500	0.2505
5.3000	0.2501

1

CASE NO. 2

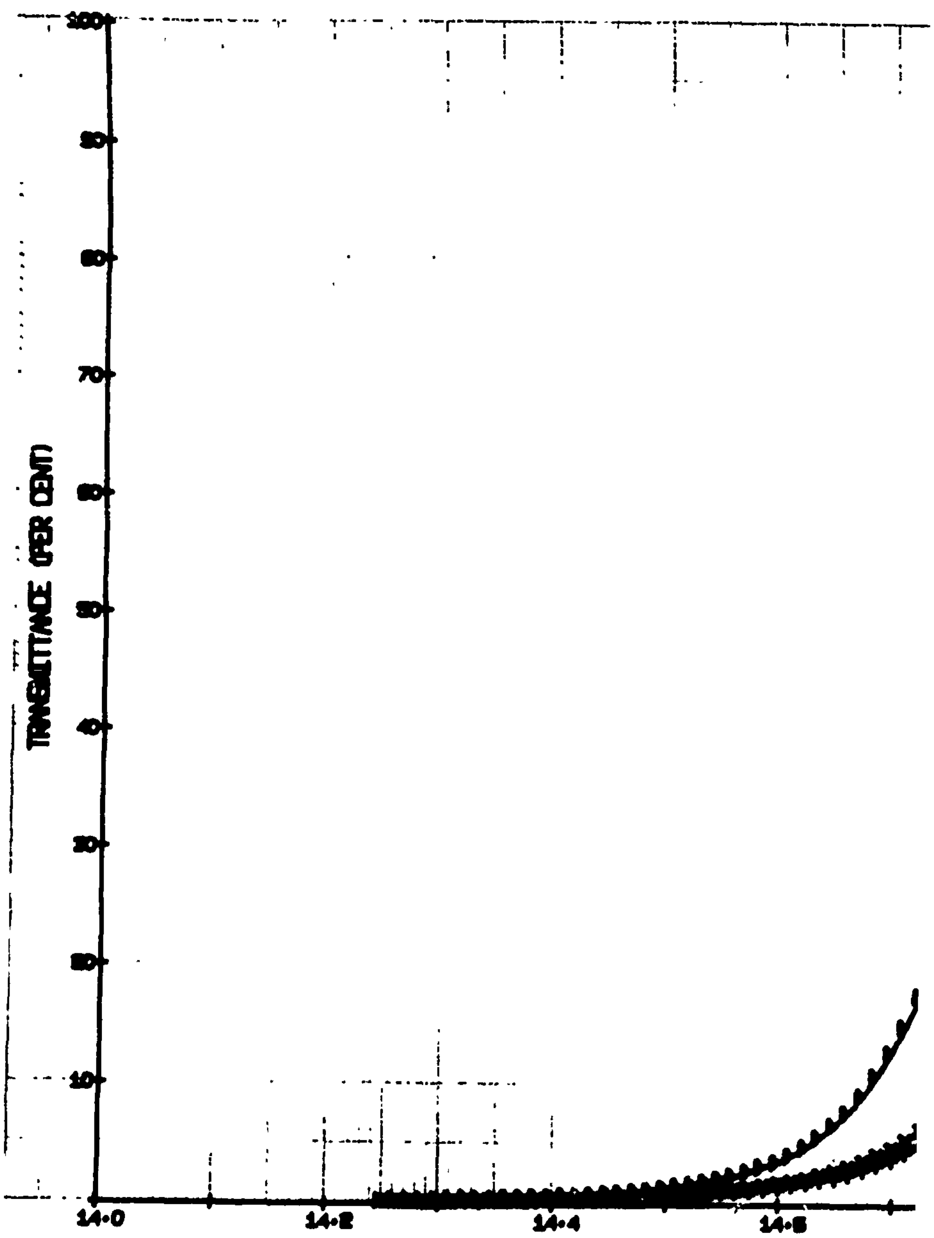
LAYER INDEX	LAYER THICKNESS
2.3500	0.2459
5.3000	0.2486
2.3500	0.2475
5.3000	0.4994
2.3500	0.2517
5.3000	0.2499
2.3500	0.2515
5.3000	0.2528
2.3500	0.2539
5.3000	0.2478
2.3500	0.2520
5.3000	0.5049
2.3500	0.2457
5.3000	0.2527

2

CASE NO. 3

LAYER INDEX	LAYER THICKNESS
2.3500	0.2490
5.3000	0.2450
2.3500	0.2584
5.300	0.5081
2.3500	0.2460
5.3000	0.2552
2.3500	0.2501
5.3000	0.2484
2.3500	0.2464
5.3000	0.2513
2.3500	0.2454
5.3000	0.4926
2.3500	0.2469
5.3000	0.2509

3



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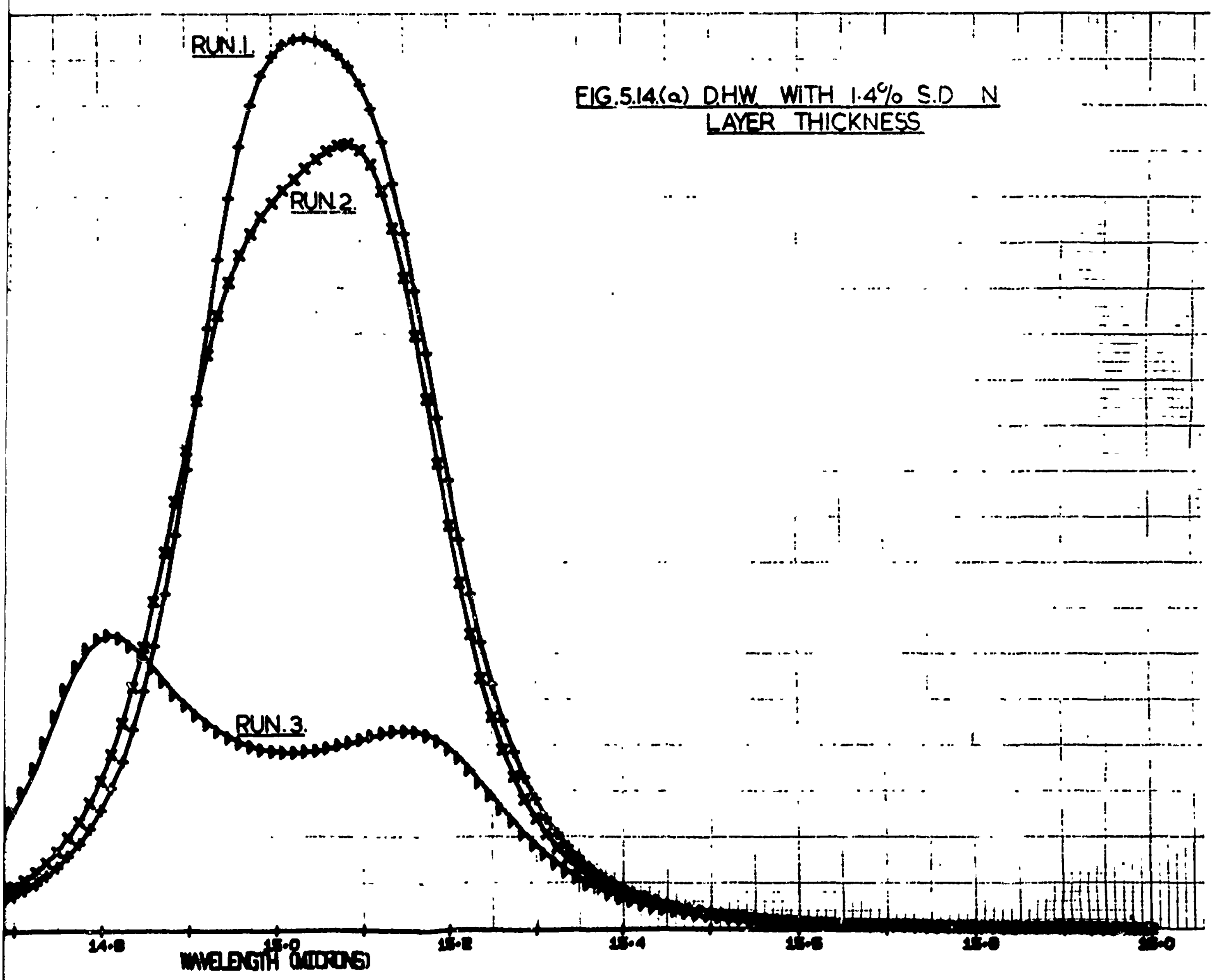

RUN.1.
RUN.2.
RUN.3.
FIG.5.14.(a) D.H.W. WITH 1·4% S.D. N
LAYER THICKNESS
14·8
15·0
15·2
15·4
15·6
15·8
16·0
WAVELENGTH (MICRONS)

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 1.4000 PER CENT

CASE NO. 1

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2464	
5.3000	0.2482	
2.3500	0.2458	
5.3000	0.5136	
2.3500	0.2496	
5.3000	0.2523	
2.3500	0.2508	4
5.3000	0.2521	
2.3500	0.2493	
5.3000	0.2494	
2.3500	0.2487	
5.3000	0.5020	
2.3500	0.2455	
5.3000	0.2500	

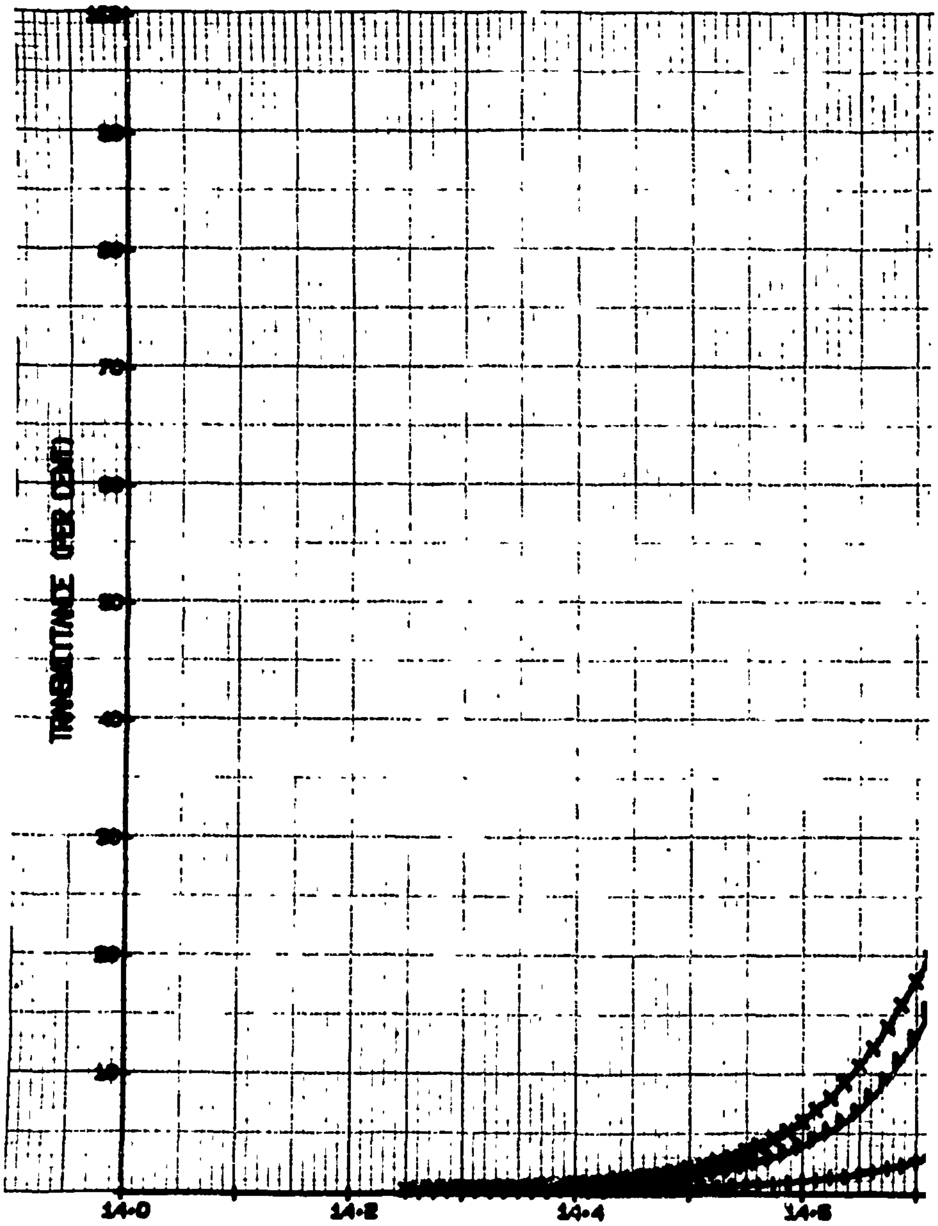
CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2432	
5.3000	0.2498	
2.3500	0.2488	
5.3000	0.4872	
2.3500	0.2482	
5.3000	0.2557	
2.3500	0.2555	5
5.3000	0.2477	
2.3500	0.2567	
5.3000	0.2475	
2.3500	0.2482	
5.3000	0.5036	
2.3500	0.2512	
5.3000	0.2534	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2515	
5.3000	0.2524	
2.3400	0.2456	
5.3000	0.4975	
2.3500	0.2477	
5.3000	0.2495	
2.3500	0.2541	6
5.3000	0.2476	
2.3500	0.2509	
5.3000	0.2501	
2.3500	0.2486	
5.3000	0.4999	
2.3500	0.2471	
5.3000	0.2507	

A



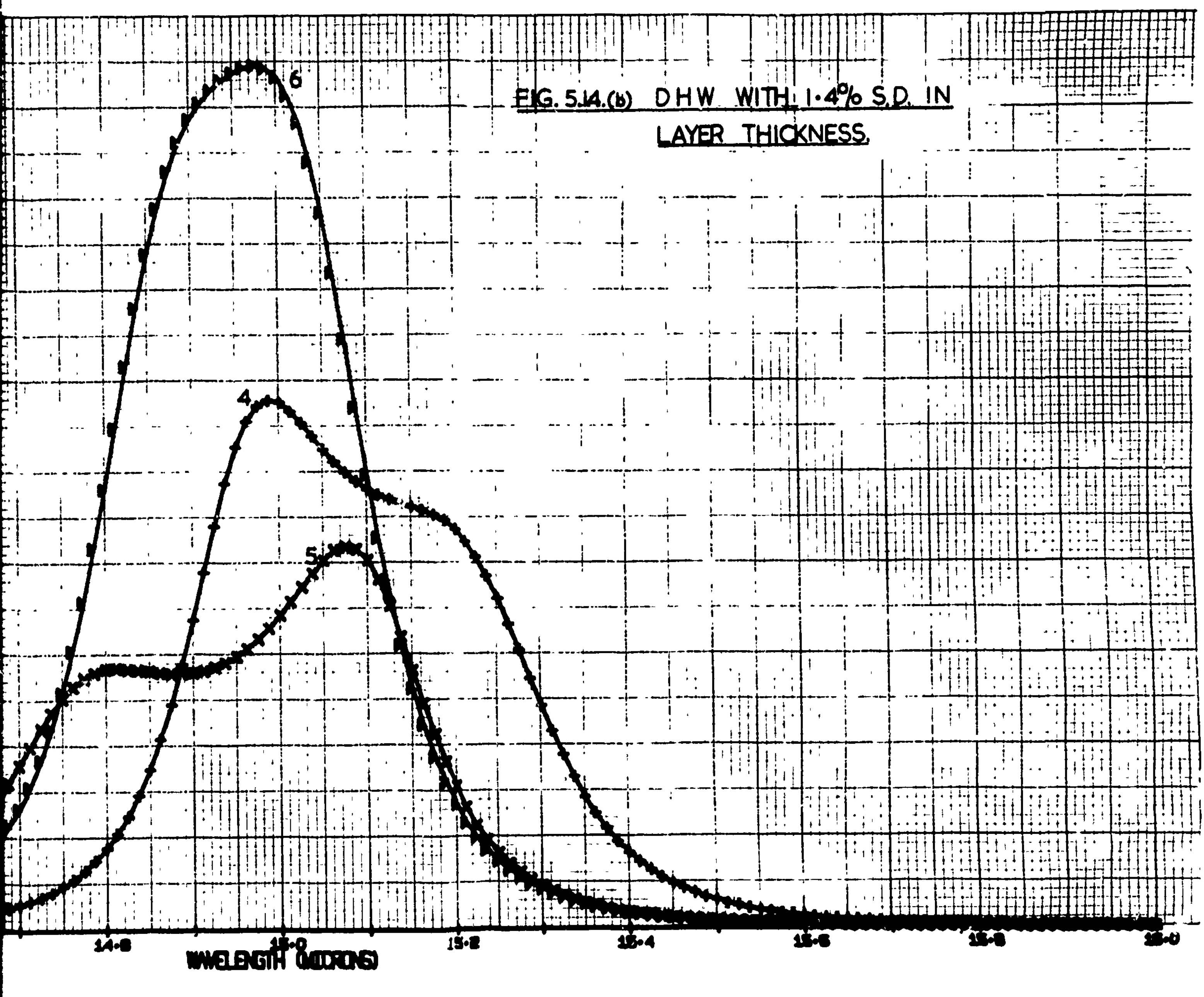


FIG. 5.14.(b) DHW WITH 1.4% S.D. IN LAYER THICKNESS.

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 1.4000 PER CENT

CASE NO. 1

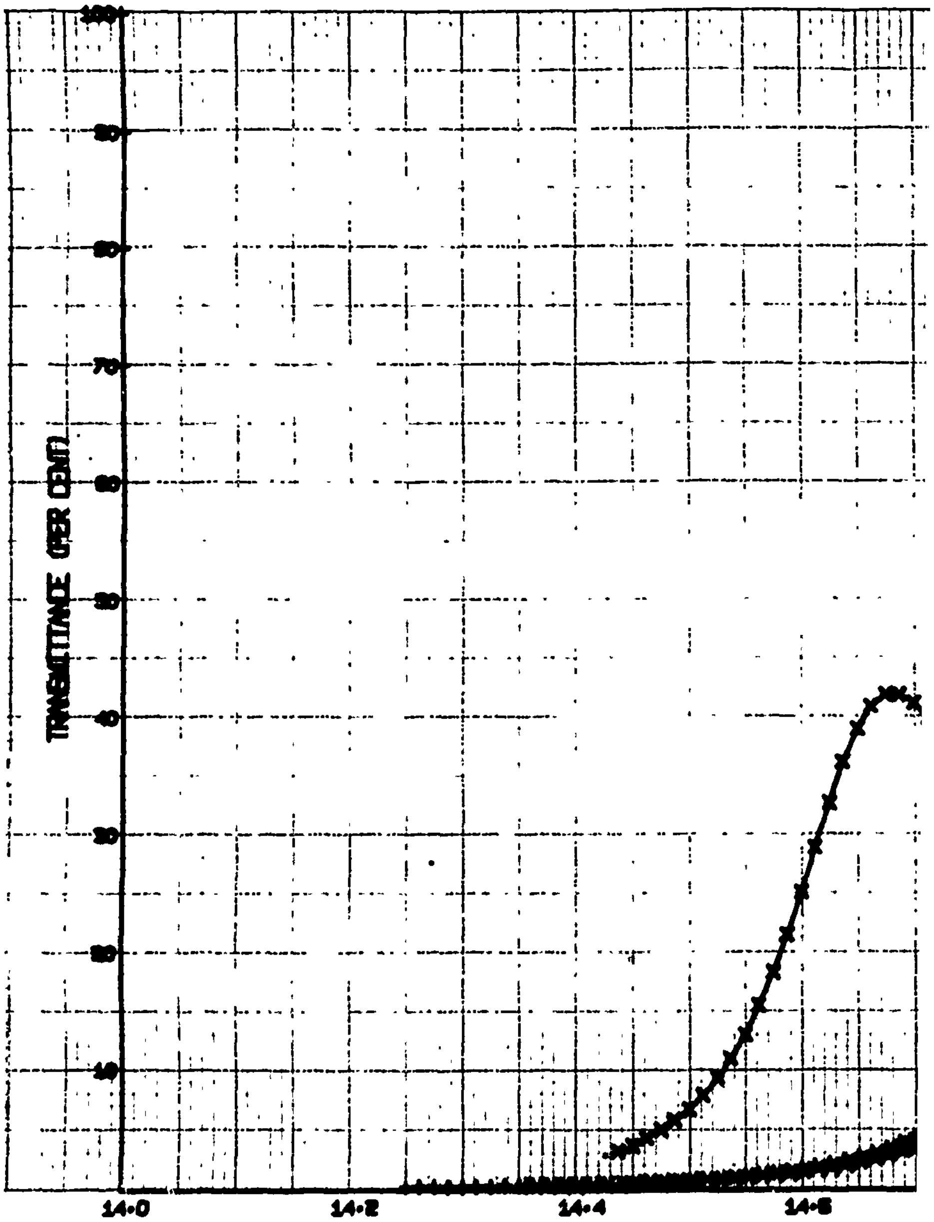
LAYER INDEX	LAYER THICKNESS	
2.3500	0.2495	
5.3000	0.2445	
2.3500	0.2537	
5.3000	0.4981	
2.3500	0.2482	
5.3000	0.2475	
2.3500	0.2540	7
5.3000	0.2538	
2.3500	0.2468	
5.3000	0.2505	
2.3500	0.2509	
5.3000	0.5102	
2.3500	0.2419	
5.3000	0.2465	

CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2513	
5.3000	0.2528	
2.3500	0.2511	
5.3000	0.4991	
2.3500	0.2447	
5.3000	0.2541	
2.3500	0.2497	8
5.3000	0.2455	
2.3500	0.2556	
5.3000	0.2518	
2.3500	0.2518	
5.3000	0.4831	
2.3500	0.2455	
5.3000	0.2461	

CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2470	
5.3000	0.2550	
2.3500	0.2528	
5.3000	0.5018	
2.3500	0.2526	
5.3000	0.2510	
2.3500	0.2532	9
5.3000	0.2451	
2.3500	0.2477	
5.3000	0.2471	
2.3500	0.2431	
5.3000	0.5068	
2.3500	0.2499	
5.3000	0.2466	



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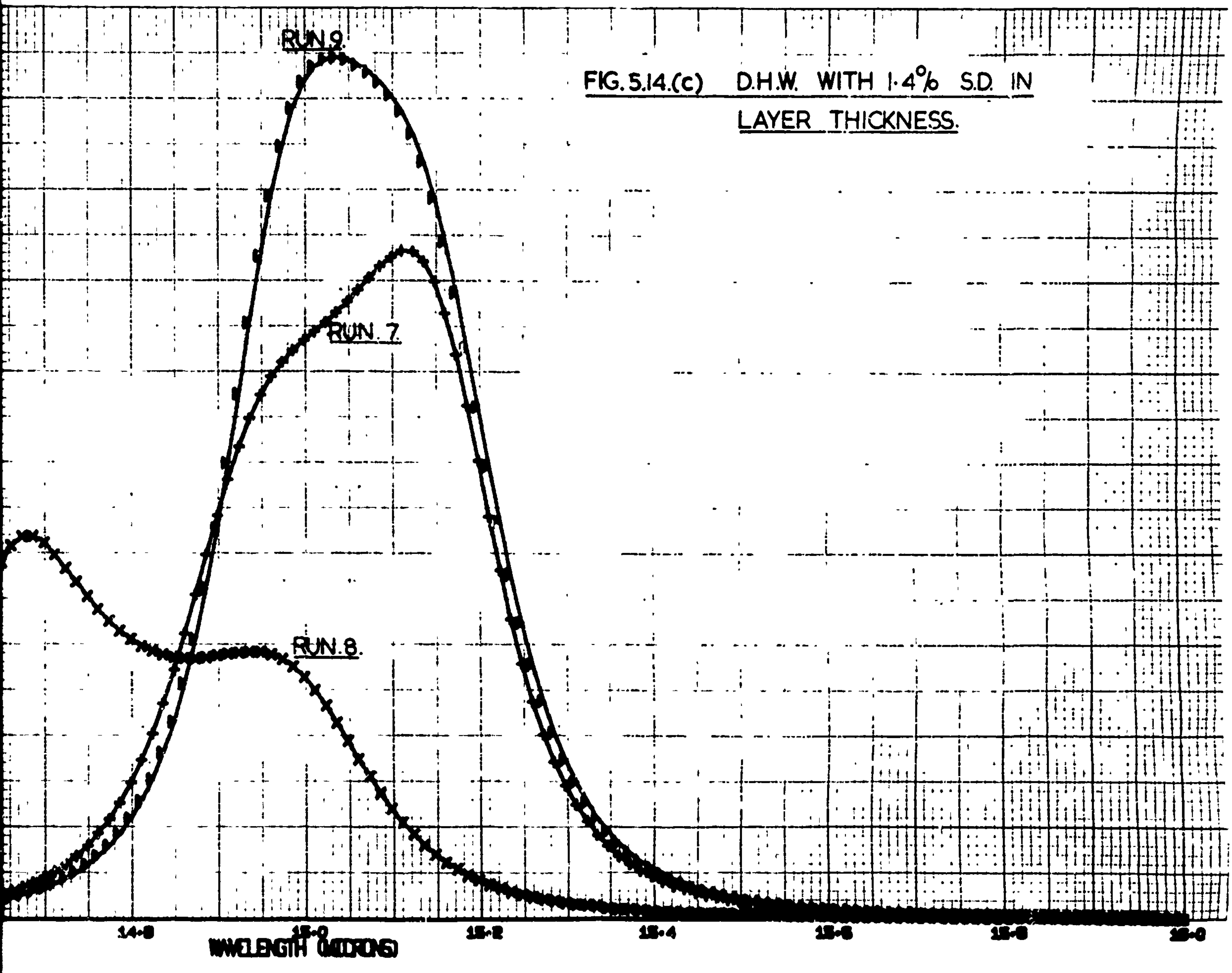


FIG. 5.14.(c) D.H.W. WITH 1·4% S.D. IN LAYER THICKNESS.

B

14-LAYER FILTER
MONITOR WAVELENGTH= 15.0000 MICRONS
RAIR= 1.0000
RSUB= 4.0000
STANDARD DEVIATION= 1.4000 PER CENT

CASE NO. 1

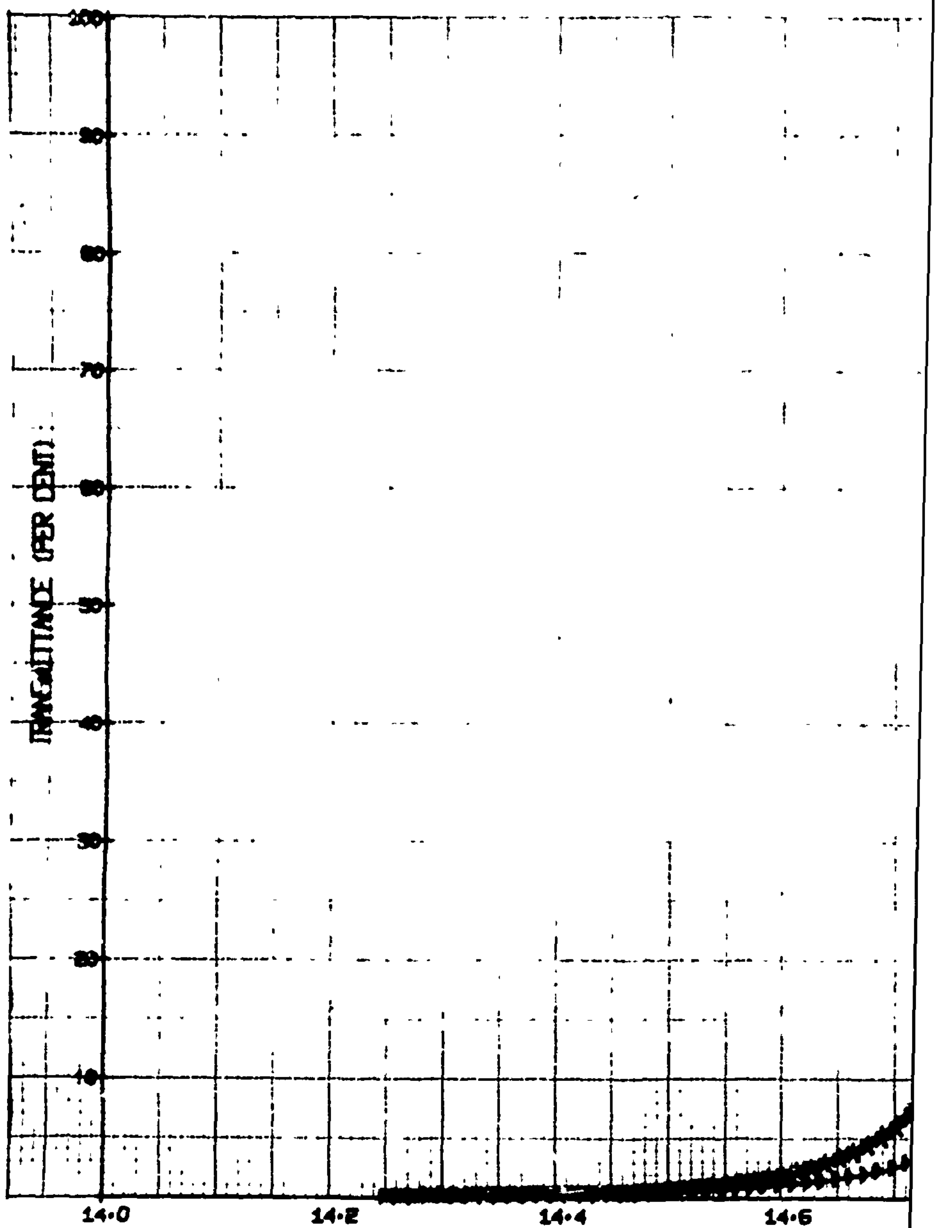
LAYER INDEX	LAYER THICKNESS	
2.3500	0.2547	
5.3000	0.2470	
2.3500	0.2532	
5.3000	0.5042	
2.3500	0.2578	
5.3000	0.2528	
2.3500	0.2510	10
5.3000	0.2526	
2.3500	0.2434	
5.3000	0.2515	
2.3500	0.2524	
5.3000	0.4922	
2.3500	0.2535	
5.3000	0.2468	

CASE NO. 2

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2538	
5.3000	0.2501	
2.3500	0.2496	
5.3000	0.5120	
2.3500	0.2516	
5.3000	0.2541	
2.3500	0.2563	11
5.3000	0.2477	
2.3500	0.2495	
5.3000	0.2475	
2.3500	0.2524	
5.3000	0.4930	
2.3500	0.2474	
5.3000	0.2515	

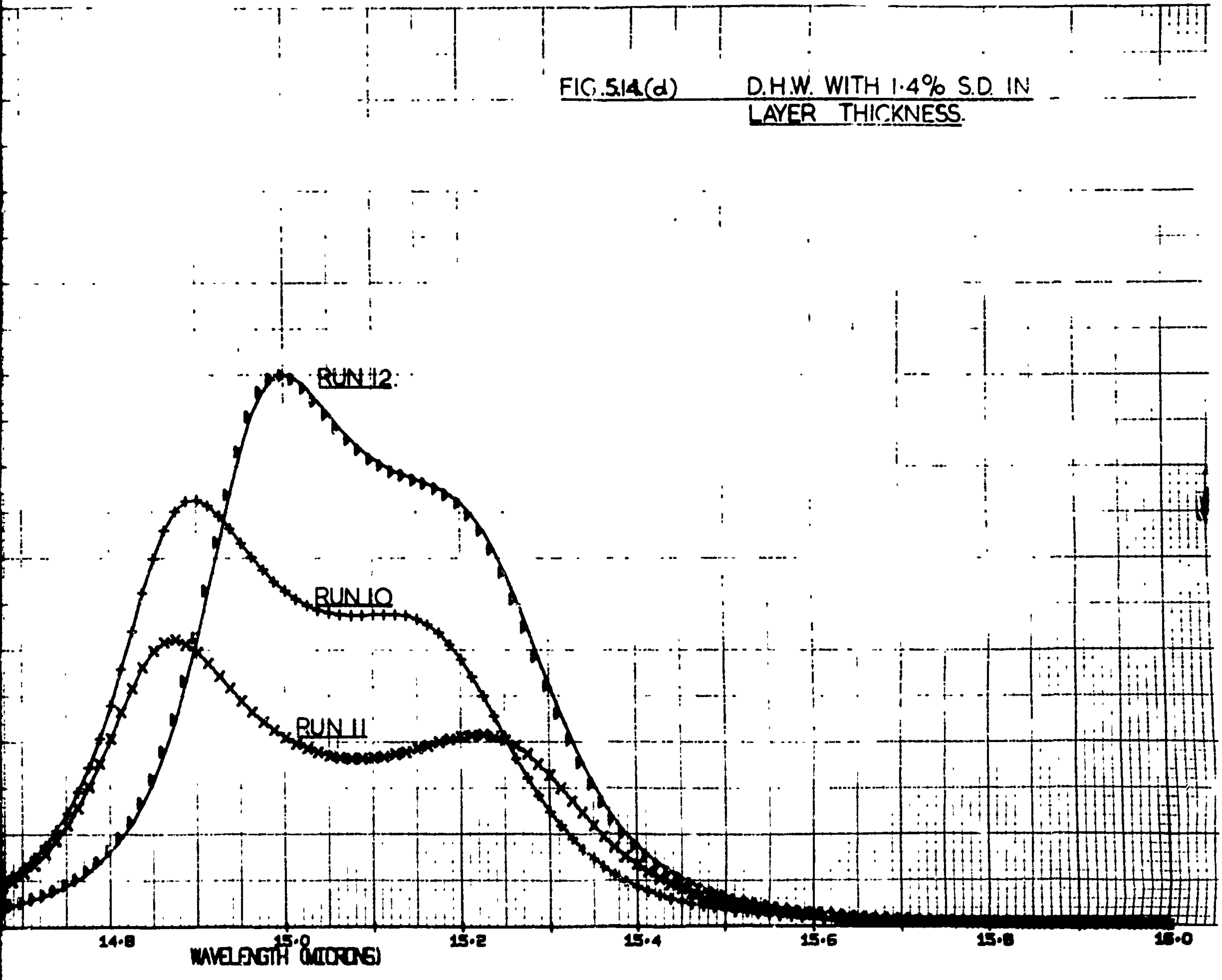
CASE NO. 3

LAYER INDEX	LAYER THICKNESS	
2.3500	0.2520	
5.3000	0.2522	
2.3500	0.2522	
5.3000	0.5111	
2.3500	0.2481	
5.3000	0.2475	
2.3500	0.2536	12
5.3000	0.2525	
2.3500	0.2512	
5.3000	0.2462	
2.3500	0.2515	
5.3000	0.4991	
2.3500	0.2508	
5.3000	0.2519	



A

FIG. 5.14(d) D.H.W. WITH 1·4% S.D. IN LAYER THICKNESS.

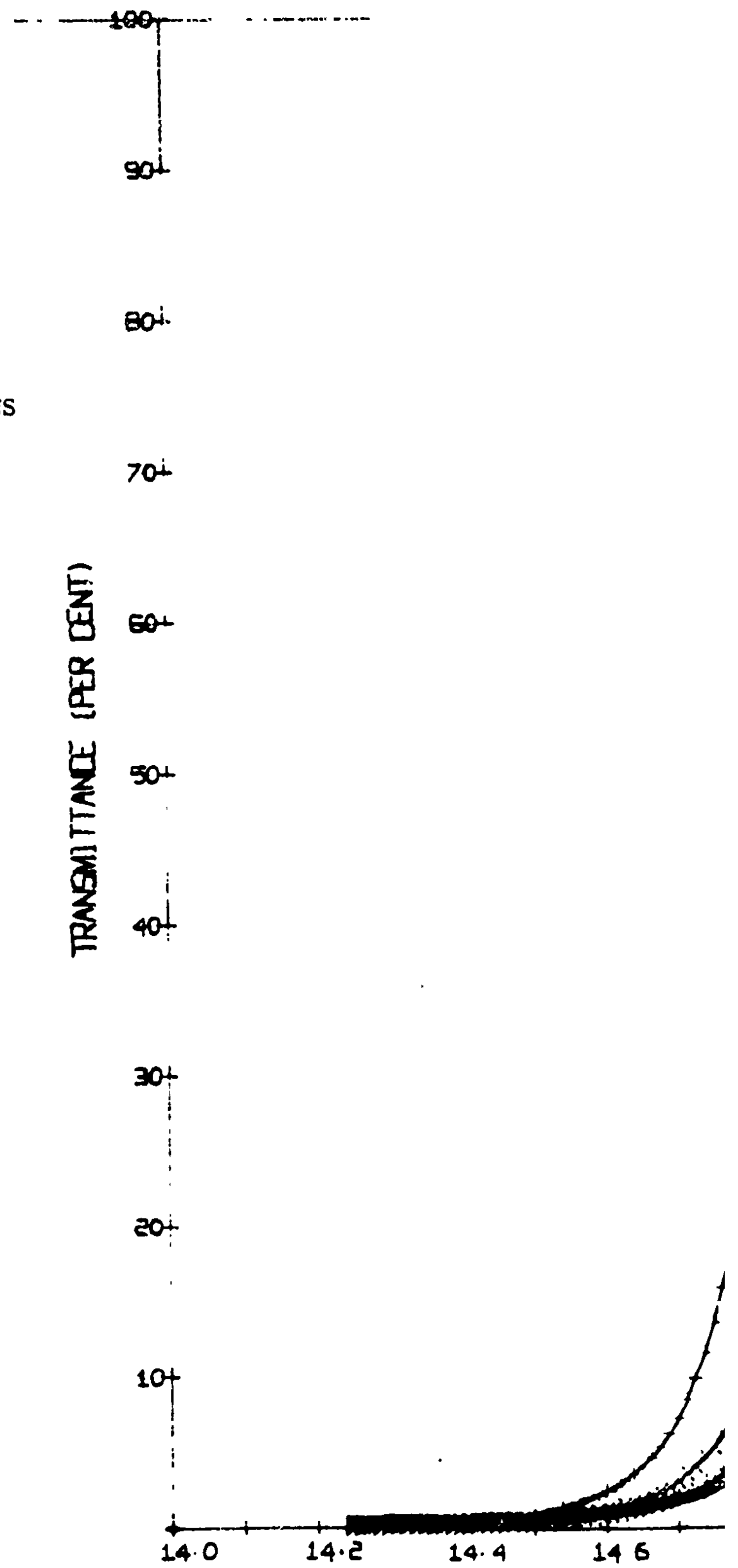


B

14-LAYER FILTER
MONITOR WAVELENGTH= 14.8200 MICRONS
RAIR= 1.0000
RSUB= 4.0000

CASE NO. 1

LAYER INDEX	LAYER THICKNESS		
2.3500	0.2464		
5.3000	0.2566		
2.3500	0.2557		
5.3000	0.5075		
2.3500	0.2467		
5.3000	0.2419		
2.3500	0.2491		
5.3000	0.2492		
2.3500	0.2604		
5.3000	0.2478		
2.3500	0.2518		
5.3000	0.5184		
2.3500	0.2564		
5.3000	0.2000	-	(1)
	0.2500	-	(2)
	0.3000	-	(3)
	0.3500	-	(4)



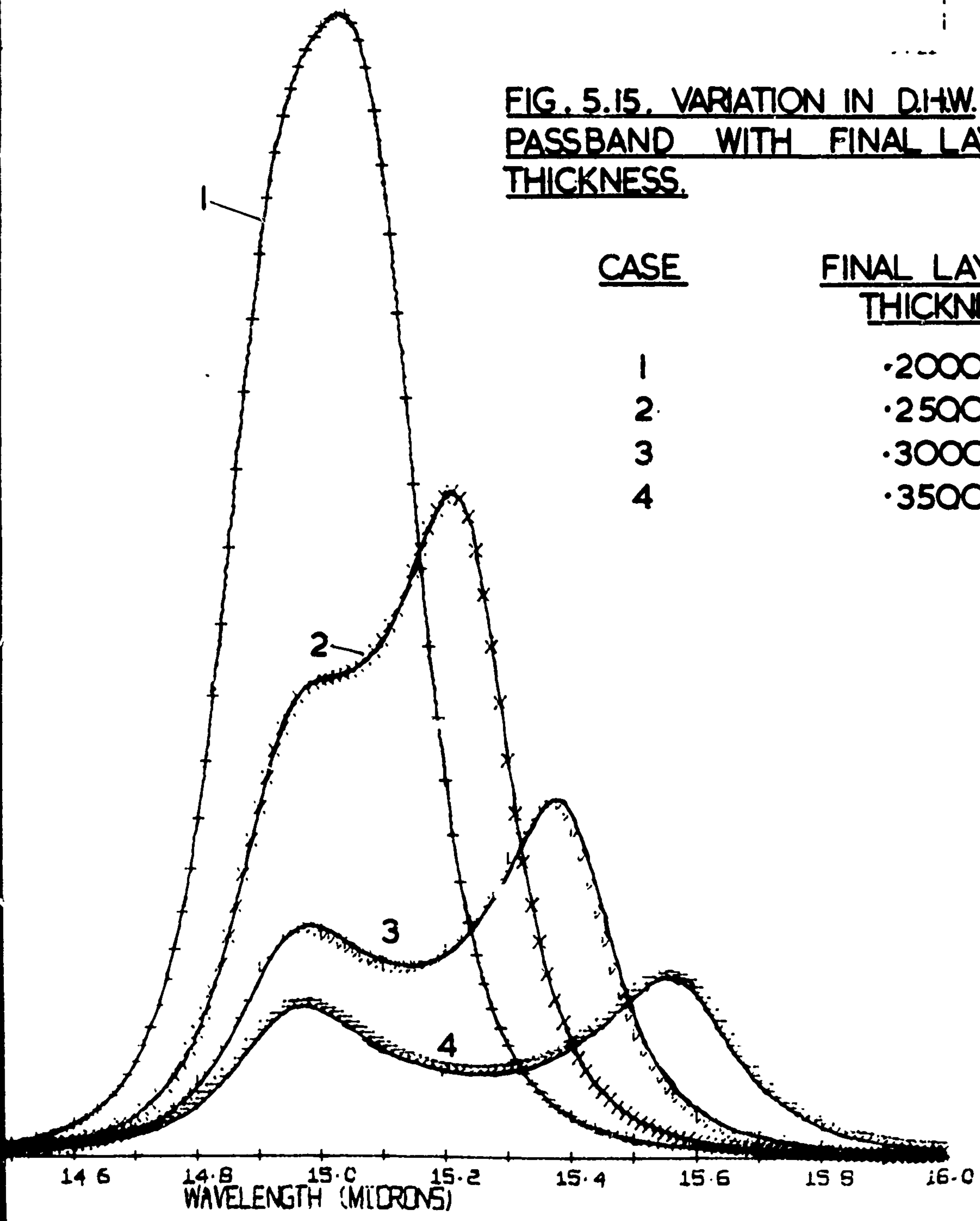
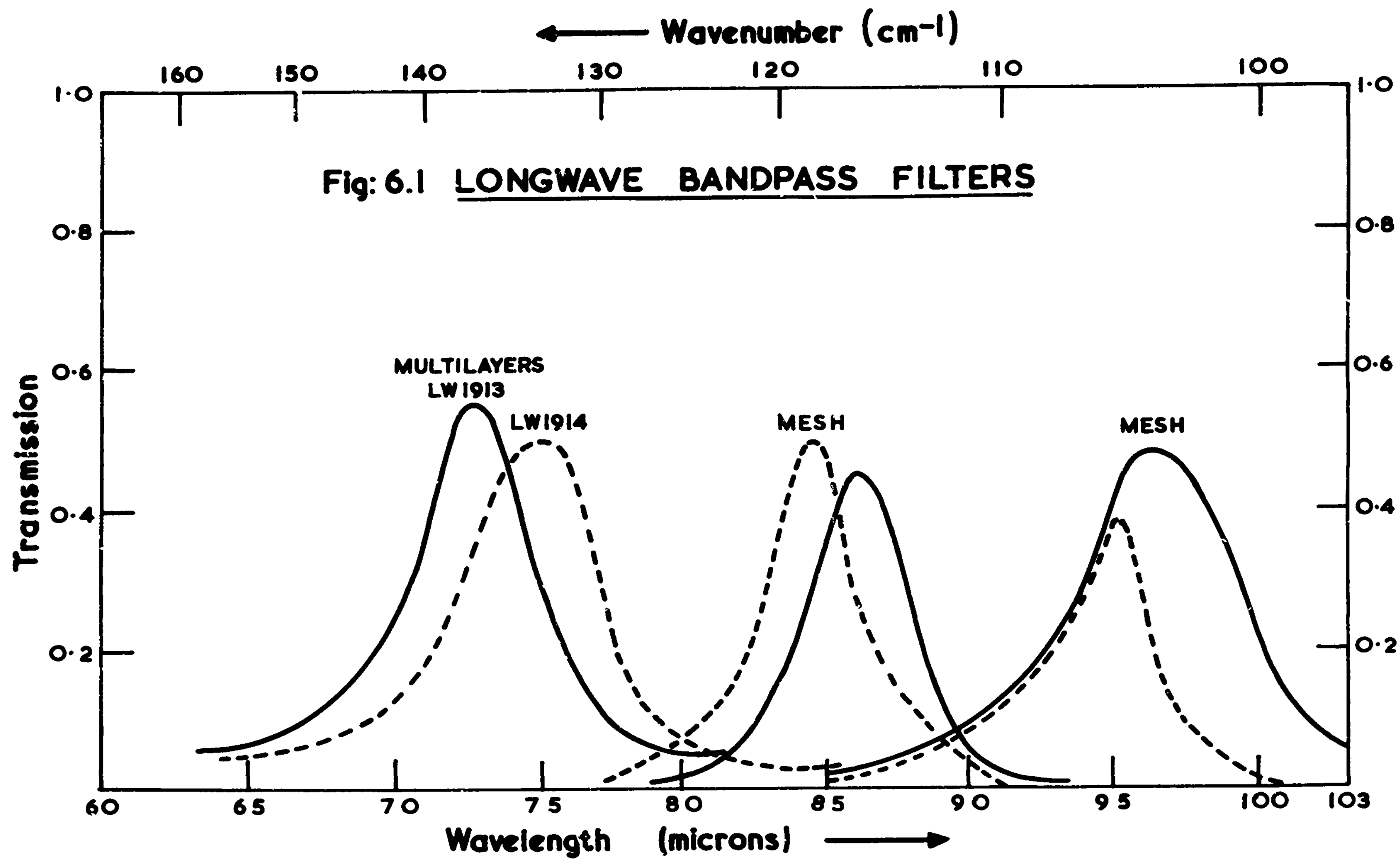


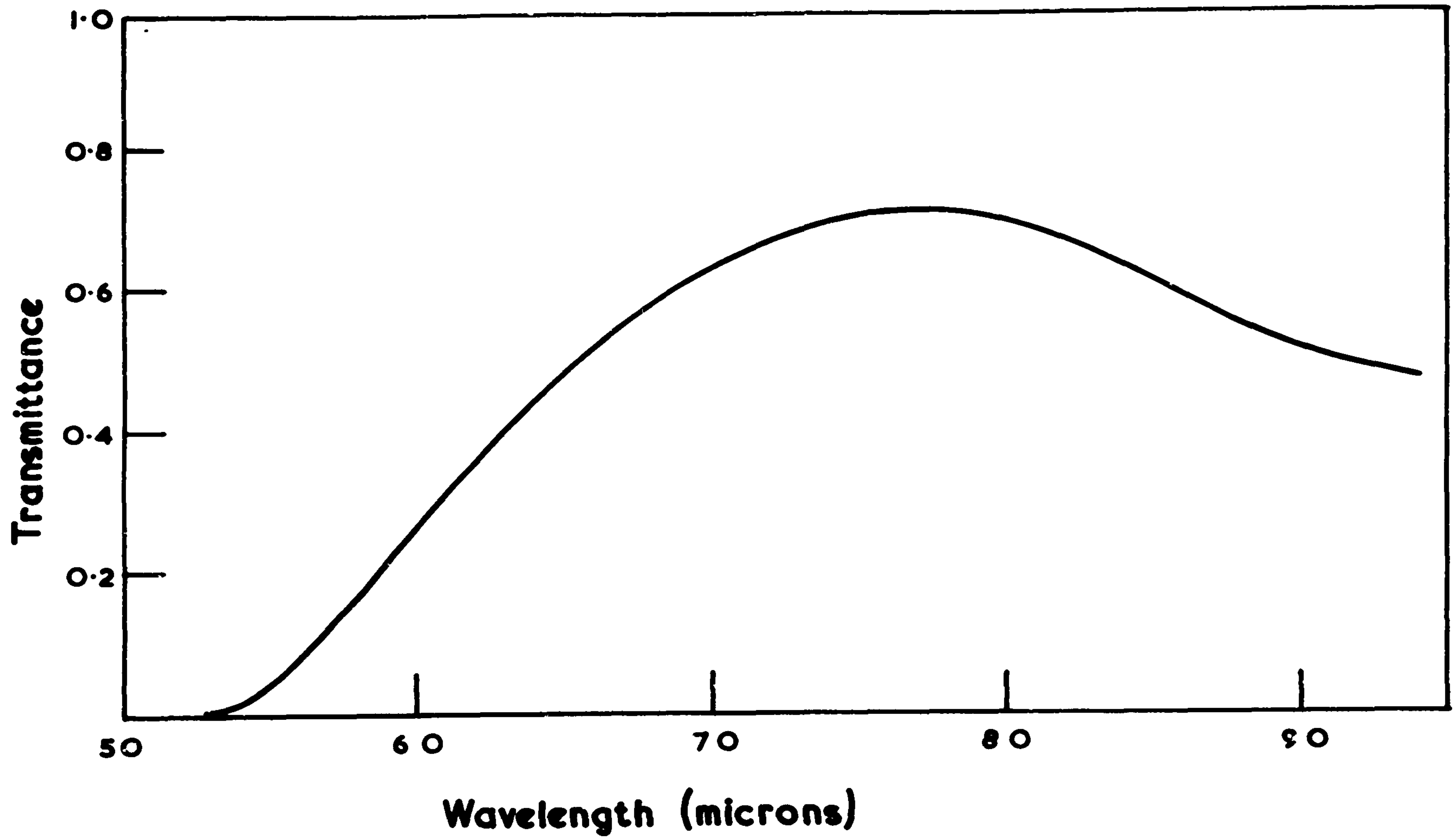
FIG. 5.15. VARIATION IN D.H.W. PASSBAND WITH FINAL LAYER THICKNESS.

B



Wavenumber (cm-1)
160
150
140
130
120
110
100
1·0
0·8
0·6
0·4
0·2
Transmission
MULTILAYERS
LW1913
LW1914
MESH
MESH
60
65
70
75
80
85
90
95
100
103
Wavelength (microns)

Fig: 6.2 LONGWAVE LOWPASS FILTER



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Scientific Final.

5 AUTHOR(S) (First name, middle initial, last name)

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13 ABSTRACT

A study of materials for multilayer evaporated film filters for the region 1-100μ has yielded several successful high index-low index combinations, notably PbTe/ZnS (5 - 25μ) and Ge/CsI (10 - 80μ).

Filters of ½% bandwidth, centred to ¼% can be produced on a routine basis for the 15μ region. Band pass filters of 10% bandwidth between 50μ and 100μ have been achieved and evaporated film and mesh techniques have overlapped in the 60-70μ region. Good blocking filters with edges out to 70μ have also been obtained with performance better than other methods of filtering for this region.

DD FORM 1 NOV 65 1473

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Multilayer filters, near infra-red, far infra-red, vacuum evaporation, micro-mesh, radiometry, semi-conductors.						